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Chapter 4 - Hydrologic Analysis and Design

4.1 Introduction

4.1.1 Purpose

The purpose of this chapter is to provide guidance for sizing runoff treatment facilities to protect the quality of receiving waters and flow control facilities for protection of stream morphology and habitat.

The chapter does *not* provide guidance for sizing flood control facilities, conveyance systems, or subsurface infiltration facilities (drywells), but these methods may be used for design of those and other stormwater infrastructure components. Contact the local jurisdiction regarding design criteria and requirements.

In the general design of flow control facilities, the optimal placement of multiple small-scale retention/infiltration facilities within a drainage area may require less total storage capacity to meet a given peak flow rate target than a single large facility at the drainage area outlet. Application of low impact development (LID) techniques may also result in decreased storage requirements; see the discussion in Chapter 2.2.6, Supplemental Guidelines.

4.1.2 Hydrologic Analysis Methods and Applicability

One or more of the following modeling methods may be approved to analyze stormwater runoff from projects for design of **runoff treatment facilities** in a jurisdiction:

- Single event hydrograph methods:
  Soil Conservation Service (SCS) Hydrograph and
  Santa Barbara Urban Hydrograph (SBUH)
- Soil Conservation Service (SCS) Curve Number Equations
- Level-Pool Routing
- Rational Method

Flow control facilities must be sized using a single event hydrograph method and level-pool routing. If available and approved, a continuous runoff model or other hydrograph modeling method may be used.

Table 4.1.1 summarizes the situations in which each of the above methods may be used. Sections 4.4 through 4.7 describe their use in greater detail.

Other hydrograph models based on peer-reviewed methods and supported by local data also may be approved by agencies or local jurisdictions; some may require special expertise and experience in their application.

Table 4.1.1 Applicability of hydrologic analysis methods for runoff treatment and flow control facility design

Method	Application and Technology Requirements
Single event hydrograph methods: Soil Conservation Service (SCS) Hydrograph *or* Santa Barbara Urban Hydrograph (SBUH)	• Allowable method for computing peak runoff rates and runoff volumes for design of runoff treatment BMPs. • Required method for design of flow control BMPs. • Requires precipitation depth and distribution. • Computer is recommended due to intensive nature of calculations. • Some SCS hydrograph models such as TR-55 are restricted to 24-hour hyetographs and will not allow the regional and short-duration storm hyetographs developed for Eastern Washington.
Soil Conservation Service (SCS) Curve Number Equations	• Allowable method for computing volumes for water quality facilities based on SCS Hydrograph method. • Requires only precipitation depth. • Can be determined using a calculator.
Level-Pool Reservoir Routing	• Required method for routing hydrograph and determining size of flow control BMPs. • Requires precipitation depth and distribution. • Input may be SCS or SBUH hydrographs. • Computer is recommended due to intensive nature of calculations.
Rational Method	• Allowable method for computing peak runoff rates for flow based water quality BMPs such as biofiltration swales and oil/water separators. • Common method for calculating peak flows for the design of drywells and conveyance systems. • Requires only precipitation depth. • Can be determined using a calculator or spreadsheet program.
Other rainfall-runoff models that generate a hydrograph	• Other models can be used if approved by the local jurisdiction and the model meets the intent of Core Element 5 and(or) Core Element 6. • Requires precipitation depth and distribution. • Computer is recommended for most models due to intensive nature of calculations.

4.1.3 Hydrologic Analysis for Core Element #5 Runoff Treatment

Runoff treatment BMPs are utilized to treat the stormwater runoff from pollutant generating surfaces. Each treatment BMP is sized based on a water quality design volume, or a water quality design flow rate. Core Element #5 Runoff Treatment in Chapter 2 identifies the design volume or flow rate that needs to be treated. Agencies and local jurisdictions should adopt criteria to provide for consistent sizing of treatment facilities (see "Treatment Facility Sizing" in section 2.2.5). Various modeling approaches can be used to determine design and sizing requirements for runoff treatment facilities; the recommended methods for predicting runoff volumes and flow rates are included in this chapter. Specific design criteria for treatment facilities also may be identified in Chapter 5 in order to achieve the performance goal of a particular BMP.

4.1.4 Hydrologic Analysis for Core Element #6 Flow Control

Flow control facilities are intended to protect stream morphology and habitat; flood control and conveyance are not addressed. Core Element #6 Flow Control in Chapter 2 identifies the requirements for hydrologic analysis when designing flow control facilities to protect stream morphology and habitat. Core Element #6 also lists projects and locations that are exempt from the flow control requirement. In order to design a flow control facility, a hydrograph model must be used to compare the pre-developed or existing condition to the proposed-development condition. An agency or local jurisdiction may impose pre-determined or other more strict pre-developed or existing condition parameters. The suggested hydrograph method is a Single Event Hydrograph such as SCS or SBUH method; agencies or local jurisdictions may adopt other methods to meet the intent of the flow control requirement and(or) they may also require more stringent design criteria. The Curve Number method may *not* be used to design flow control facilities.

4.2 Design Storm Distributions

The design storms to be used in eastern Washington specify:

- Total rainfall volume (depth in inches), and
- Rainfall distribution (dimensionless).

The following sections explain total rainfall depth and rainfall distribution associated with a design storm. The design storm event is also specified by return period (months and/or years) and duration.

All rainfall-runoff hydrograph methods require the input of a rainfall distribution or design storm hyetograph. The hyetograph represents the portion of the total rainfall depth that falls during each increment of time for a given overall duration. It is usually presented as a dimensionless plot or table of unit rainfall depth (incremental rainfall depth for each time interval divided by the total rainfall depth) versus time.

These are the design storm distribution or rainfall depth options and the design problems for which they may be applied:

1. The 3-hour **short-duration storm** distribution, for design of flow-rate-based treatment BMPs.
2. The 24-hour or longer **regional storm** distribution (based on the 72-hour long-duration storm for each region), for design of flow control facilities and volume-based treatment BMPs.
3. The 24-hour **SCS Type IA storm** distribution, for design of flow control facilities in Regions 2 & 3 and volume-based treatment BMPs.

4. The **modified 24-hour SCS Type IA storm** distribution, for design of flow control facilities at small (less than one acre) projects in Regions 1 & 4 and volume-based treatment BMPs.
5. The 24-hour **SCS Type II storm** distribution, for design of volume-based and flow-rate-based treatment BMPs.
6. **One-half inch of runoff** from the site, depth only, no distribution; to be used only for determining runoff treatment volumes and only for projects located in Regions 2 & 3.
7. The **2-year mean precipitation depth** (no distribution), to be used only for determining peak flow rate by the Rational Method in designing flow-rate-based treatment BMPs.
8. **Other design criteria** adopted by agencies or local jurisdictions that meet or exceed the intent of the Core Elements for Runoff Treatment and Flow Control.

Options 1 through 5 are discussed in further detail in the following three sections. Tabular values for the hyetographs associated with these storms are provided in tables 4.2.2 through 4.2.8 at the end of the sections.

4.2.1 Short-Duration and Regional Design Storms

Rainfall patterns during storms in eastern Washington were analyzed to identify short-duration and regional rainfall distributions for regions of eastern Washington (see Appendix 4A). Two main storm types are of interest to hydrologic analysis for design of stormwater facilities in eastern Washington: the thunderstorms and general storms. The former is represented by the **short-duration storm** distribution and the latter is represented by the **regional storm** distribution. These design storms were developed in a manner that replicated temporal characteristics observed in storms from climatologically similar areas in and near eastern Washington. See Appendix 4A for further discussion of the development and review of these design storms. Appendix 4A.2 includes a graphical representation of the standard SCS Type IA and II synthetic design storms and the long-duration storms for comparison on a unit basis.

Thunderstorms can occur in the late spring through early-fall seasons and are characterized by high intensities for short periods of time over localized areas. These types of storms can produce high rates of runoff and flash flooding in urban areas and are important where flood peak discharge and/or erosion are design considerations. The effect of these storms should also be considered in designing facilities based on other design storms.

General storms can occur at anytime of the year, but are more common in the late fall through winter period, and in the late spring and early summer periods. General storms in eastern Washington are characterized by sequences of storms and intervening dry periods, often occurring over several days. Low to moderate intensity precipitation is typical during the periods of storm activity. These types of events can produce floods with moderate peak discharge and large runoff volumes. The runoff volume can be augmented by snowmelt when precipitation falls on snow during winter and early spring storms. These types of storm events are important where both runoff volume and peak discharge are design considerations.

Thunderstorms typically generate the greatest peak discharges for small urban watersheds. Use of short-duration storms is appropriate for design of conveyance structures and flow-rate-based treatment facilities including biofiltration swales.

General storms typically generate the greatest runoff volume. Use of the regional design storms is appropriate for design of stormwater detention and water quality treatment facilities where total runoff volume is the primary concern, and for flow control facilities where both the quantity and timing of runoff are of concern.

When utilizing these design storms, note that eastern Washington has been divided into four climatic regions to reflect the differences in storm characteristics and the seasonality of storms (see Figure 4.3.1). The four climatic regions are:

- **Region 1 – East Slopes of Cascade Mountains:** this region is comprised of mountain areas on the east slopes of the Cascade Mountains. It is bounded to the west by the Cascade crest and generally bounded to the east by the contour line of 16-inches average annual precipitation.
- **Region 2 – Central Basin:** this region is comprised of the Columbia Basin and adjacent low elevation areas in central Washington. It is generally bounded to the west by the contour line of 16-inches average annual precipitation at the base of the east slopes of the Cascade Mountains. The region is bounded to the north and east by the contour line of 14-inches average annual precipitation. The majority of the area in this region receives about eight inches of average annual precipitation. Many of the larger cities in eastern Washington are in this region including: Ellensburg, Kennewick, Moses Lake, Pasco, Richland, Wenatchee, and Yakima.
- **Region 3 – Okanogan, Spokane, Palouse:** this region is comprised of inter-mountain areas and includes areas near Okanogan, Spokane, and the Palouse. It is bounded to the northwest by the contour line of 16-inches average annual precipitation at the base of the east slopes of the Cascade Mountains. It is bounded to the south and west by the contour line of 12-inches average annual precipitation at the eastern edge of the Central Basin. It is bounded to the northeast by the Kettle River Range and Selkirk Mountains at approximately the contour line of 22-inches average annual

precipitation. It is bounded to the southeast by the Blue Mountains also at the contour line of 22-inches average annual precipitation.

- **Region 4 – Northeastern Mountains and Blue Mountains:** this region is comprised of mountain areas in the easternmost part of Washington State. It includes portions of the Kettle River Range and Selkirk Mountains in the northeast, and includes the Blue Mountains in the southeast corner of eastern Washington. Average annual precipitation ranges from a minimum of 22-inches to over 60-inches. The western boundary of this region is the contour line of 22-inches average annual precipitation.

Short-Duration Design Storm

Short durations, high intensity, and smaller volumes relative to general storms characterize summer thunderstorms. The short-duration storm hyetograph is 3 hours in duration. The storm temporal pattern is shown in Figure 4.2.1 as a unit hyetograph. Tabular values for this hyetograph are listed in Table 4.2.4. Total precipitation is 1.06 times the 2-hour precipitation amount. There is one short-duration storm for all climate regions in eastern Washington.

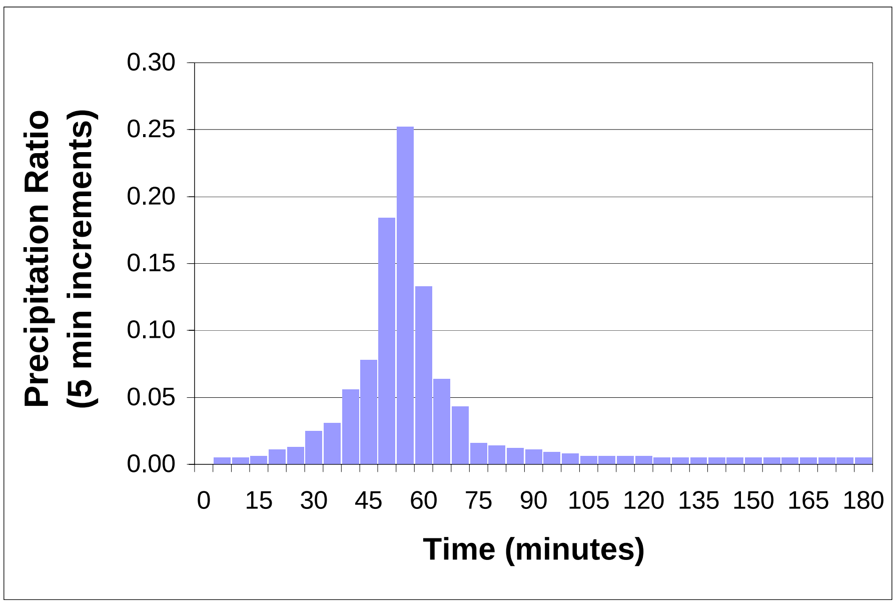


Figure 4.2.1 Short-duration storm unit hyetograph

Regional Storm

The general storm is characterized by lower rainfall intensities and larger volumes in a pattern that varies by region. The synthetic distribution represents a series of two rainfall events separated by a dry intervening period and occurring during a total 72-hour period of time. A sample 72-hour long-duration storm hyetograph is shown in Figure 4.2.2.

The regional storms are derived from these hyetographs (see Appendix 4A). The first, smaller precipitation event (occurring from 6 to 21 hours in Figure 4.2.2) is generally insufficient to generate runoff that is present when the larger second precipitation event commences and for that reason it is deemed unnecessary to directly model the smaller precipitation event and only the second, larger portion (beginning at 36 hours in Figure 4.2.2) is directly modeled. However, the soil wetting produced by the first event must still be accounted for by appropriately adjusting the modeling input parameters.

Tabular values of the regional storm hyetographs are listed in Tables 4.2.5 through 4.2.8. The regional storms are similar to the 24-hour SCS Type IA storm distribution. An adapted version of applying the Type IA distribution is discussed in section 4.2.3. Comparison of precipitation depths, antecedent moisture conditions, and necessary adjustments and modeling requirements for the regional storms are discussed in the section on the Modified SCS Type IA design storm, section 4.2.3.

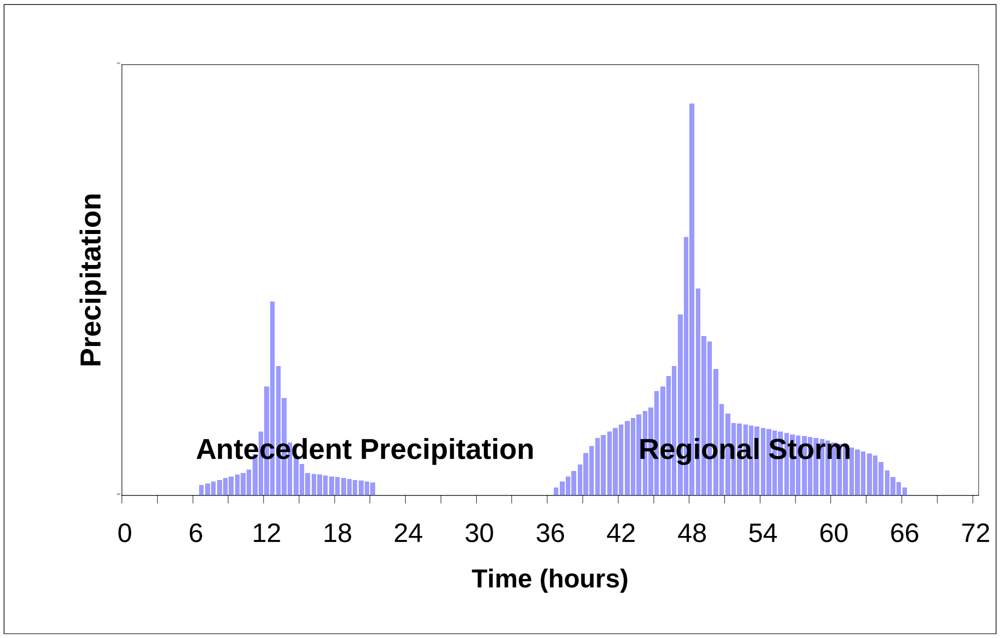


Figure 4.2.2 Sample regional storm hyetograph. The regional storm utilizes only the second event of the "long-duration storm" hyetograph, following the dry period and beginning at about 36 hours.

4.2.2 SCS Type II and Type IA Standard Design Storms

Note: *the U.S. Soil Conservation Service (SCS) is now known as the Natural Resources Conservation Service, or NRCS.*

These are two of the four standard 24-hour rainfall distributions that are commonly used in SCS hydrograph methods.

The **SCS Type II** hyetograph has a high intensity peak. It has been utilized in eastern Washington since the 1970s and is also used throughout much of the United States. The SCS Type II standard rainfall distribution does not match historical records for the two main storm types of interest to hydrologic analysis for design of stormwater facilities in eastern Washington: the short-duration thunderstorm and the long-duration general storm.

The **SCS Type IA** hyetograph has lower rainfall intensities and was originally identified by SCS as applicable to western Washington and the eastern slopes of the Cascade Mountains. The SCS Type IA storm is similar to the four regional storms and recent analysis supports the direct application of this hyetograph throughout eastern Washington; see Appendix 4A.2. The following section describes a modified application that incorporates information from the historical analysis.

See Figures 4.2.3 and 4.2.4 for graphical representations of these two SCS hyetographs. Tabular values of these hyetographs are in Tables 4.2.2 and 4.2.3. See Appendix 4A.2 for a graphical representation of these two storms and the long-duration storms for comparison on a unit basis.

4.2.3 Modified SCS Type IA and Regional Design Storms

The modified SCS Type IA design storm is an adapted application of the standard SCS Type IA design storm intended to more closely reflect historical precipitation patterns in eastern Washington. Antecedent moisture conditions and precipitation depths are modified to reflect more typical conditions.

Various agencies and local jurisdictions may choose to implement either the regional design storms (discussed in section 4.2.1) or the SCS Type IA design storm. Since the regional storms have more total precipitation but are spread over more time than the 24-hour SCS Type IA, the computed peak flows and volumes tend to be reasonably similar. For Region 2, there are no measurable differences in precipitation total or duration. For Regions 3 and 4, the differences in rainfall depth are minor: total precipitation is no more than 7% greater than the standard 24-hour SCS Type IA storm; the durations are several hours longer. For Region 1, the differences are greatest: a 16% increase in precipitation depth compared to the 24-hour SCS Type IA storm, and more than 40% longer duration.

If the 24-hour SCS Type IA storm is used directly, the precipitation totals are the 24-hour amounts without adjustment. If the modified Type IA is used, the precipitation totals need to be adjusted as indicated in Table 4.2.10 in section 4.2.5; these adjustment factors are also in the notes in Tables 4.2.5 through 4.2.8.

The prior soil wetting produced by the previous storm event in the long-duration storm (the portion that is not included in the modeling exercise) still needs to be accounted for by appropriately adjusting the modeling input parameters. Regardless of whether the 24-hour SCS Type IA or regional storm hyetographs are used for modeling, this adjustment must be made. The amount of antecedent precipitation can be expressed as a percentage of the total precipitation modeled, as shown in Table 4.2.1.

Table 4.2.1 Antecedent precipitation prior to regional storm

Region #	Region Name	Antecedent precipitation as percentage of 24-hour SCS Type IA Storm precipitation
1	East Slope Cascades	33%
2	Central Basin	19%
3	Okanogan, Spokane, Palouse	27%
4	NE & Blue Mountains	36%

Region #	Region Name	Antecedent precipitation as percentage of regional long-duration storm hyetograph precipitation
1	East Slope Cascades	28%
2	Central Basin	19%
3	Okanogan, Spokane, Palouse	25%
4	NE & Blue Mountains	34%

Curve number adjustments based on engineering analysis and judgment of the antecedent precipitation, soils characteristics, and surface conditions must be considered. The Antecedent Moisture Condition discussion in this chapter (see section 4.5.3) is one basis for adjustment. Another is the use of the Soil Conservation Service county surveys that include estimates of permeability and/or infiltration rates.

Precipitation magnitudes and frequencies are adjusted as discussed in section 4.2.5.

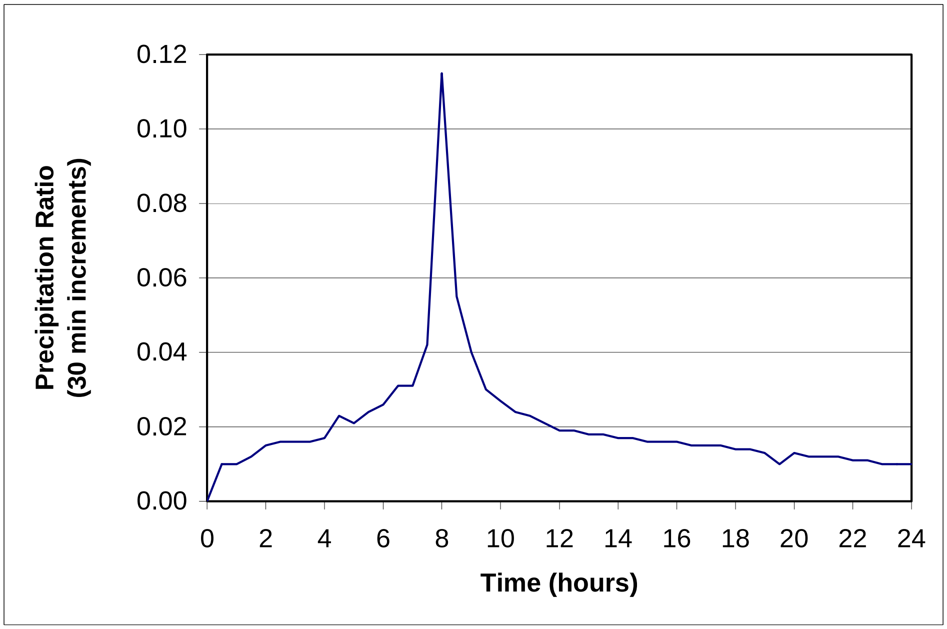


Figure 4.2.3 SCS Type IA Hyetograph

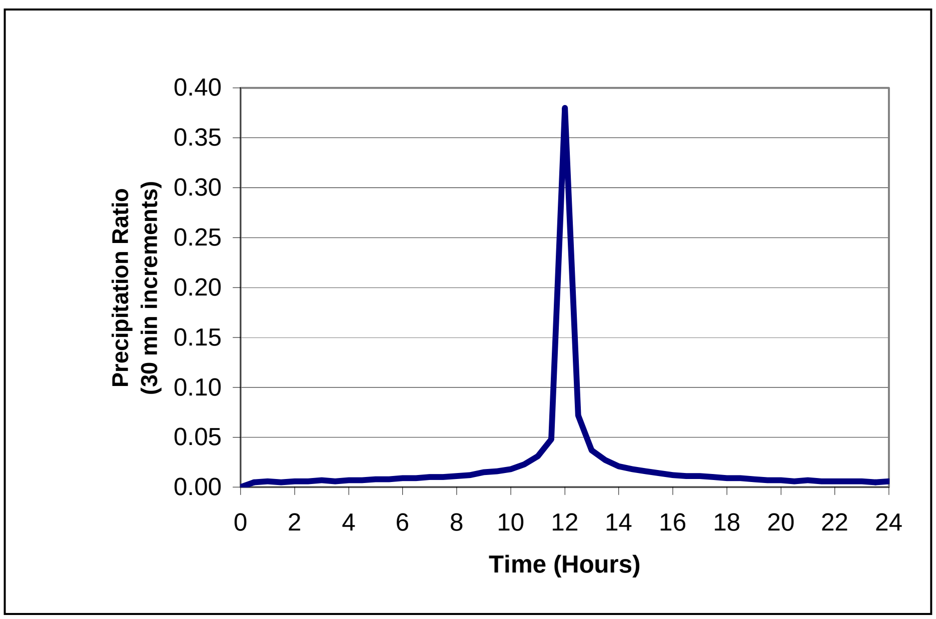


Figure 4.2.4 SCS Type II Hyetograph

Table 4.2.2 SCS Type IA Storm Hyetograph Values

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall	Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall	Time (0.1 hours)	Incrementa l Rainfall	Cumulative Rainfall
0.0	0.000	0.000	4.5	0.004	0.135	9.0	0.007	0.520
0.1	0.002	0.002	4.6	0.004	0.139	9.1	0.007	0.527
0.2	0.002	0.004	4.7	0.004	0.143	9.2	0.006	0.533
0.3	0.002	0.006	4.8	0.004	0.147	9.3	0.006	0.539
0.4	0.002	0.008	4.9	0.005	0.152	9.4	0.006	0.545
0.5	0.002	0.010	5.0	0.004	0.156	9.5	0.005	0.550
0.6	0.002	0.012	5.1	0.005	0.161	9.6	0.006	0.556
0.7	0.002	0.014	5.2	0.004	0.165	9.7	0.005	0.561
0.8	0.002	0.016	5.3	0.005	0.170	9.8	0.006	0.567
0.9	0.002	0.018	5.4	0.005	0.175	9.9	0.005	0.572
1.0	0.002	0.020	5.5	0.005	0.180	10.0	0.005	0.577
1.1	0.003	0.023	5.6	0.005	0.185	10.1	0.005	0.582
1.2	0.003	0.026	5.7	0.005	0.190	10.2	0.005	0.587
1.3	0.003	0.029	5.8	0.005	0.195	10.3	0.005	0.592
1.4	0.003	0.032	5.9	0.005	0.200	10.4	0.004	0.596
1.5	0.003	0.035	6.0	0.006	0.206	10.5	0.005	0.601
1.6	0.003	0.038	6.1	0.006	0.212	10.6	0.005	0.606
1.7	0.003	0.041	6.2	0.006	0.218	10.7	0.004	0.610
1.8	0.003	0.044	6.3	0.006	0.224	10.8	0.005	0.615
1.9	0.003	0.047	6.4	0.007	0.231	10.9	0.005	0.620
2.0	0.003	0.050	6.5	0.006	0.237	11.0	0.004	0.624
2.1	0.003	0.053	6.6	0.006	0.243	11.1	0.004	0.628
2.2	0.003	0.056	6.7	0.006	0.249	11.2	0.005	0.633
2.3	0.004	0.060	6.8	0.006	0.255	11.3	0.004	0.637
2.4	0.003	0.063	6.9	0.006	0.261	11.4	0.004	0.641
2.5	0.003	0.066	7.0	0.007	0.268	11.5	0.004	0.645
2.6	0.003	0.069	7.1	0.007	0.275	11.6	0.004	0.649
2.7	0.003	0.072	7.2	0.008	0.283	11.7	0.004	0.653
2.8	0.004	0.076	7.3	0.008	0.291	11.8	0.004	0.657
2.9	0.003	0.079	7.4	0.009	0.300	11.9	0.003	0.660
3.0	0.003	0.082	7.5	0.010	0.310	12.0	0.004	0.664
3.1	0.003	0.085	7.6	0.021	0.331	12.1	0.004	0.668
3.2	0.003	0.088	7.7	0.024	0.355	12.2	0.003	0.671
3.3	0.003	0.091	7.8	0.024	0.379	12.3	0.004	0.675
3.4	0.004	0.095	7.9	0.024	0.403	12.4	0.004	0.679
3.5	0.003	0.098	8.0	0.022	0.425	12.5	0.004	0.683
3.6	0.003	0.101	8.1	0.014	0.439	12.6	0.004	0.687
3.7	0.004	0.105	8.2	0.013	0.452	12.7	0.003	0.690
3.8	0.004	0.109	8.3	0.010	0.462	12.8	0.004	0.694
3.9	0.003	0.112	8.4	0.010	0.472	12.9	0.003	0.697
4.0	0.004	0.116	8.5	0.008	0.480	13.0	0.004	0.701
4.1	0.004	0.120	8.6	0.009	0.489	13.1	0.004	0.705
4.2	0.003	0.123	8.7	0.009	0.498	13.2	0.003	0.708
4.3	0.004	0.127	8.8	0.007	0.505	13.3	0.004	0.712
4.4	0.004	0.131	8.9	0.008	0.513	13.4	0.004	0.716

Table 4.2.2 (continued) SCS Type IA Storm Hyetograph Values

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
13.5	0.003	0.719
13.6	0.003	0.722
13.7	0.004	0.726
13.8	0.003	0.729
13.9	0.004	0.733
14.0	0.003	0.736
14.1	0.003	0.739
14.2	0.004	0.743
14.3	0.003	0.746
14.4	0.003	0.749
14.5	0.004	0.753
14.6	0.003	0.756
14.7	0.003	0.759
14.8	0.004	0.763
14.9	0.003	0.766
15.0	0.003	0.769
15.1	0.003	0.772
15.2	0.004	0.776
15.3	0.003	0.779
15.4	0.003	0.782
15.5	0.003	0.785
15.6	0.003	0.788
15.7	0.004	0.792
15.8	0.003	0.795
15.9	0.003	0.798
16.0	0.003	0.801
16.1	0.003	0.804
16.2	0.003	0.807
16.3	0.003	0.810
16.4	0.003	0.813
16.5	0.003	0.816
16.6	0.003	0.819
16.7	0.003	0.822
16.8	0.003	0.825
16.9	0.003	0.828
17.0	0.003	0.831
17.1	0.003	0.834
17.2	0.003	0.837
17.3	0.003	0.840
17.4	0.003	0.843
17.5	0.003	0.846
17.6	0.003	0.849
17.7	0.002	0.851
17.8	0.003	0.854
17.9	0.003	0.857

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
18.0	0.003	0.860
18.1	0.003	0.863
18.2	0.002	0.865
18.3	0.003	0.868
18.4	0.003	0.871
18.5	0.003	0.874
18.6	0.002	0.876
18.7	0.003	0.879
18.8	0.003	0.882
18.9	0.002	0.884
19.0	0.003	0.887
19.1	0.003	0.890
19.2	0.002	0.892
19.3	0.003	0.895
19.4	0.002	0.897
19.5	0.003	0.900
19.6	0.003	0.903
19.7	0.002	0.905
19.8	0.003	0.908
19.9	0.002	0.910
20.0	0.003	0.913
20.1	0.002	0.915
20.2	0.003	0.918
20.3	0.002	0.920
20.4	0.002	0.922
20.5	0.003	0.925
20.6	0.002	0.927
20.7	0.003	0.930
20.8	0.002	0.932
20.9	0.002	0.934
21.0	0.003	0.937
21.1	0.002	0.939
21.2	0.002	0.941
21.3	0.003	0.944
21.4	0.002	0.946
21.5	0.002	0.948
21.6	0.003	0.951
21.7	0.002	0.953
21.8	0.002	0.955
21.9	0.002	0.957
22.0	0.002	0.959
22.1	0.003	0.962
22.2	0.002	0.964
22.3	0.002	0.966
22.4	0.002	0.968

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
22.5	0.002	0.970
22.6	0.002	0.972
22.7	0.002	0.974
22.8	0.002	0.976
22.9	0.002	0.978
23.0	0.002	0.980
23.1	0.002	0.982
23.2	0.002	0.984
23.3	0.002	0.986
23.4	0.002	0.988
23.5	0.002	0.990
23.6	0.002	0.992
23.7	0.002	0.994
23.8	0.002	0.996
23.9	0.002	0.998
24.0	0.002	1.000

Table 4.2.3 SCS Type II Storm Hyetograph Values

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.000	0.000
0.1	0.001	0.001
0.2	0.001	0.002
0.3	0.001	0.003
0.4	0.001	0.004
0.5	0.001	0.005
0.6	0.001	0.006
0.7	0.001	0.007
0.8	0.001	0.008
0.9	0.001	0.009
1.0	0.002	0.011
1.1	0.001	0.012
1.2	0.001	0.013
1.3	0.001	0.014
1.4	0.001	0.015
1.5	0.001	0.016
1.6	0.001	0.017
1.7	0.001	0.018
1.8	0.002	0.020
1.9	0.001	0.021
2.0	0.001	0.022
2.1	0.001	0.023
2.2	0.001	0.024
2.3	0.002	0.026
2.4	0.001	0.027
2.5	0.001	0.028
2.6	0.001	0.029
2.7	0.002	0.031
2.8	0.001	0.032
2.9	0.001	0.033
3.0	0.002	0.035
3.1	0.001	0.036
3.2	0.001	0.037
3.3	0.001	0.038
3.4	0.002	0.040
3.5	0.001	0.041
3.6	0.001	0.042
3.7	0.002	0.044
3.8	0.001	0.045
3.9	0.002	0.047
4.0	0.001	0.048
4.1	0.001	0.049
4.2	0.002	0.051
4.3	0.001	0.052
4.4	0.002	0.054

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
4.5	0.001	0.055
4.6	0.002	0.057
4.7	0.001	0.058
4.8	0.002	0.060
4.9	0.001	0.061
5.0	0.002	0.063
5.1	0.002	0.065
5.2	0.001	0.066
5.3	0.002	0.068
5.4	0.002	0.070
5.5	0.001	0.071
5.6	0.002	0.073
5.7	0.002	0.075
5.8	0.001	0.076
5.9	0.002	0.078
6.0	0.002	0.080
6.1	0.002	0.082
6.2	0.002	0.084
6.3	0.001	0.085
6.4	0.002	0.087
6.5	0.002	0.089
6.6	0.002	0.091
6.7	0.002	0.093
6.8	0.002	0.095
6.9	0.002	0.097
7.0	0.002	0.099
7.1	0.002	0.101
7.2	0.002	0.103
7.3	0.002	0.105
7.4	0.002	0.107
7.5	0.002	0.109
7.6	0.002	0.111
7.7	0.002	0.113
7.8	0.003	0.116
7.9	0.002	0.118
8.0	0.002	0.120
8.1	0.002	0.122
8.2	0.003	0.125
8.3	0.002	0.127
8.4	0.003	0.130
8.5	0.002	0.132
8.6	0.003	0.135
8.7	0.003	0.138
8.8	0.003	0.141
8.9	0.003	0.144

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
9.0	0.003	0.147
9.1	0.003	0.150
9.2	0.003	0.153
9.3	0.004	0.157
9.4	0.003	0.160
9.5	0.003	0.163
9.6	0.003	0.166
9.7	0.004	0.170
9.8	0.003	0.173
9.9	0.004	0.177
10.0	0.004	0.181
10.1	0.004	0.185
10.2	0.004	0.189
10.3	0.005	0.194
10.4	0.005	0.199
10.5	0.005	0.204
10.6	0.005	0.209
10.7	0.006	0.215
10.8	0.006	0.221
10.9	0.007	0.228
11.0	0.007	0.235
11.1	0.008	0.243
11.2	0.008	0.251
11.3	0.010	0.261
11.4	0.010	0.271
11.5	0.012	0.283
11.6	0.024	0.307
11.7	0.047	0.354
11.8	0.077	0.431
11.9	0.137	0.568
12.0	0.095	0.663
12.1	0.019	0.682
12.2	0.017	0.699
12.3	0.014	0.713
12.4	0.012	0.725
12.5	0.010	0.735
12.6	0.008	0.743
12.7	0.008	0.751
12.8	0.008	0.759
12.9	0.007	0.766
13.0	0.006	0.772
13.1	0.006	0.778
13.2	0.006	0.784
13.3	0.005	0.789
13.4	0.005	0.794

Table 4.2.3 (continued) SCS Type II Storm Hyetograph Values

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
13.5	0.005	0.799
13.6	0.005	0.804
13.7	0.004	0.808
13.8	0.004	0.812
13.9	0.004	0.816
14.0	0.004	0.820
14.1	0.004	0.824
14.2	0.003	0.827
14.3	0.004	0.831
14.4	0.003	0.834
14.5	0.004	0.838
14.6	0.003	0.841
14.7	0.003	0.844
14.8	0.003	0.847
14.9	0.003	0.850
15.0	0.004	0.854
15.1	0.002	0.856
15.2	0.003	0.859
15.3	0.003	0.862
15.4	0.003	0.865
15.5	0.003	0.868
15.6	0.002	0.870
15.7	0.003	0.873
15.8	0.002	0.875
15.9	0.003	0.878
16.0	0.002	0.880
16.1	0.002	0.882
16.2	0.003	0.885
16.3	0.002	0.887
16.4	0.002	0.889
16.5	0.002	0.891
16.6	0.002	0.893
16.7	0.002	0.895
16.8	0.003	0.898
16.9	0.002	0.900
17.0	0.002	0.902
17.1	0.002	0.904
17.2	0.002	0.906
17.3	0.002	0.908
17.4	0.002	0.910
17.5	0.002	0.912
17.6	0.002	0.914
17.7	0.001	0.915
17.8	0.002	0.917
17.9	0.002	0.919

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
18.0	0.002	0.921
18.1	0.002	0.923
18.2	0.002	0.925
18.3	0.001	0.926
18.4	0.002	0.928
18.5	0.002	0.930
18.6	0.001	0.931
18.7	0.002	0.933
18.8	0.002	0.935
18.9	0.001	0.936
19.0	0.002	0.938
19.1	0.001	0.939
19.2	0.002	0.941
19.3	0.001	0.942
19.4	0.002	0.944
19.5	0.001	0.945
19.6	0.002	0.947
19.7	0.001	0.948
19.8	0.001	0.949
19.9	0.002	0.951
20.0	0.001	0.952
20.1	0.001	0.953
20.2	0.002	0.955
20.3	0.001	0.956
20.4	0.001	0.957
20.5	0.001	0.958
20.6	0.002	0.960
20.7	0.001	0.961
20.8	0.001	0.962
20.9	0.002	0.964
21.0	0.001	0.965
21.1	0.001	0.966
21.2	0.001	0.967
21.3	0.001	0.968
21.4	0.002	0.970
21.5	0.001	0.971
21.6	0.001	0.972
21.7	0.001	0.973
21.8	0.002	0.975
21.9	0.001	0.976
22.0	0.001	0.977
22.1	0.001	0.978
22.2	0.001	0.979
22.3	0.002	0.981
22.4	0.001	0.982

Time (0.1 hours)	Incremental Rainfall	Cumulative Rainfall
22.5	0.001	0.983
22.6	0.001	0.984
22.7	0.001	0.985
22.8	0.001	0.986
22.9	0.002	0.988
23.0	0.001	0.989
23.1	0.001	0.990
23.2	0.001	0.991
23.3	0.001	0.992
23.4	0.001	0.993
23.5	0.001	0.994
23.6	0.002	0.996
23.7	0.001	0.997
23.8	0.001	0.998
23.9	0.001	0.999
24.0	0.001	1.000

Table 4.2.4 Short-Duration Storm Hyetograph Values for All Regions

Note: Use the 2-hour precipitation value times 1.06 to determine the 3-hour total precipitation amount.

Time (minutes)	Time (hours)	Incremental Rainfall	Cumulative Rainfall
0	0	0.0000	0.0000
5	0.08	0.0047	0.0047
10	0.17	0.0047	0.0094
15	0.25	0.0057	0.0151
20	0.33	0.0104	0.0255
25	0.42	0.0123	0.0378
30	0.50	0.0236	0.0614
35	0.58	0.0292	0.0906
40	0.67	0.0528	0.1434
45	0.75	0.0736	0.2170
50	0.83	0.1736	0.3906
55	0.92	0.2377	0.6283
60	1.00	0.1255	0.7538
65	1.08	0.0604	0.8142
70	1.17	0.0406	0.8548
75	1.25	0.0151	0.8699
80	1.33	0.0132	0.8831
85	1.42	0.0113	0.8944
90	1.50	0.0104	0.9048
95	1.58	0.0085	0.9133
100	1.67	0.0075	0.9208
105	1.75	0.0057	0.9265
110	1.83	0.0057	0.9322
115	1.92	0.0057	0.9379
120	2.00	0.0057	0.9436
125	2.08	0.0047	0.9483
130	2.17	0.0047	0.9530
135	2.25	0.0047	0.9577
140	2.33	0.0047	0.9624
145	2.42	0.0047	0.9671
150	2.50	0.0047	0.9718
155	2.58	0.0047	0.9765
160	2.67	0.0047	0.9812
165	2.75	0.0047	0.9859
170	2.83	0.0047	0.9906
175	2.92	0.0047	0.9953
180	3.00	0.0047	1.0000

Table 4.2.5 Regional Storm Hyetograph Values for Region 1: Cascade Mountains

Note: Use the 24-hour precipitation value times 1.16 to determine the long-duration storm total precipitation amount.

Time (hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.0000	0.0000
0.5	0.0024	0.0024
1.0	0.0036	0.0060
1.5	0.0040	0.0101
2.0	0.0047	0.0148
2.5	0.0051	0.0199
3.0	0.0054	0.0253
3.5	0.0058	0.0311
4.0	0.0062	0.0374
4.5	0.0066	0.0439
5.0	0.0078	0.0517
5.5	0.0096	0.0614
6.0	0.0120	0.0733
6.5	0.0138	0.0871
7.0	0.0150	0.1022
7.5	0.0157	0.1179
8.0	0.0164	0.1343
8.5	0.0171	0.1513
9.0	0.0178	0.1691
9.5	0.0185	0.1876
10.0	0.0192	0.2067
10.5	0.0198	0.2266
11.0	0.0205	0.2471
11.5	0.0212	0.2683
12.0	0.0220	0.2904

Time (hours)	Incremental Rainfall	Cumulative Rainfall
12.5	0.0226	0.3130
13.0	0.0235	0.3364
13.5	0.0243	0.3608
14.0	0.0297	0.3905
14.5	0.0338	0.4243
15.0	0.0507	0.4750
15.5	0.0315	0.5066
16.0	0.0283	0.5349
16.5	0.0257	0.5606
17.0	0.0231	0.5837
17.5	0.0214	0.6051
18.0	0.0183	0.6234
18.5	0.0168	0.6402
19.0	0.0165	0.6566
19.5	0.0161	0.6728
20.0	0.0158	0.6886
20.5	0.0154	0.7040
21.0	0.0151	0.7191
21.5	0.0148	0.7339
22.0	0.0144	0.7483
22.5	0.0141	0.7623
23.0	0.0137	0.7761
23.5	0.0134	0.7894
24.0	0.0130	0.8025
24.5	0.0127	0.8151

Time (hours)	Incremental Rainfall	Cumulative Rainfall
25.0	0.0123	0.8275
25.5	0.0120	0.8395
26.0	0.0117	0.8512
26.5	0.0115	0.8627
27.0	0.0112	0.8739
27.5	0.0110	0.8849
28.0	0.0107	0.8956
28.5	0.0104	0.9060
29.0	0.0102	0.9162
29.5	0.0099	0.9261
30.0	0.0097	0.9358
30.5	0.0088	0.9446
31.0	0.0079	0.9525
31.5	0.0071	0.9596
32.0	0.0063	0.9659
32.5	0.0058	0.9717
33.0	0.0054	0.9772
33.5	0.0050	0.9822
34.0	0.0047	0.9869
34.5	0.0043	0.9912
35.0	0.0039	0.9950
35.5	0.0030	0.9981
36.0	0.0019	1.0000

Table 4.2.6 Regional Storm Hyetograph Values for Region 2: Central Basin

Note: Use the 24-hour precipitation value (times 1.00) to determine the long-duration storm total precipitation amount.

Time (hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.0000	0.0000
0.5	0.0054	0.0054
1.0	0.0086	0.0140
1.5	0.0100	0.0240
2.0	0.0120	0.0360
2.5	0.0130	0.0490
3.0	0.0140	0.0630
3.5	0.0150	0.0780
4.0	0.0160	0.0940
4.5	0.0170	0.1110
5.0	0.0187	0.1297
5.5	0.0228	0.1525
6.0	0.0283	0.1808
6.5	0.0305	0.2113
7.0	0.0335	0.2448
7.5	0.0365	0.2813
8.0	0.0484	0.3297
8.5	0.0622	0.3919
9.0	0.0933	0.4852
9.5	0.0527	0.5380
10.0	0.0402	0.5782
10.5	0.0372	0.6154
11.0	0.0348	0.6502
11.5	0.0331	0.6833
12.0	0.0289	0.7122
12.5	0.0252	0.7374
13.0	0.0219	0.7593
13.5	0.0191	0.7783
14.0	0.0167	0.7950
14.5	0.0148	0.8098
15.0	0.0134	0.8232
15.5	0.0123	0.8355
16.0	0.0116	0.8471
16.5	0.0110	0.8581
17.0	0.0105	0.8686
17.5	0.0103	0.8789
18.0	0.0103	0.8892
18.5	0.0104	0.8996
19.0	0.0105	0.9100
19.5	0.0105	0.9205
20.0	0.0104	0.9309
20.5	0.0102	0.9412
21.0	0.0100	0.9512
21.5	0.0097	0.9609
22.0	0.0093	0.9702
22.5	0.0087	0.9789
23.0	0.0083	0.9872
23.5	0.0078	0.9950
24.0	0.0050	1.0000

Table 4.2.7 Regional Storm Hyetograph Values for Region 3: Okanogan, Spokane, Palouse

Note: Use the 24-hour precipitation value times 1.06 to determine long-duration storm total precipitation amount.

Time (hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.0000	0.0000
0.5	0.0017	0.0017
1.0	0.0030	0.0047
1.5	0.0041	0.0088
2.0	0.0053	0.0141
2.5	0.0068	0.0209
3.0	0.0092	0.0301
3.5	0.0108	0.0409
4.0	0.0126	0.0535
4.5	0.0132	0.0667
5.0	0.0139	0.0806
5.5	0.0147	0.0952
6.0	0.0154	0.1106
6.5	0.0162	0.1268
7.0	0.0169	0.1437
7.5	0.0177	0.1614
8.0	0.0184	0.1798
8.5	0.0192	0.1990
9.0	0.0228	0.2219
9.5	0.0238	0.2457
10.0	0.0260	0.2717
10.5	0.0282	0.2999
11.0	0.0395	0.3394
11.5	0.0564	0.3958
12.0	0.0855	0.4813
12.5	0.0451	0.5265
13.0	0.0348	0.5612
13.5	0.0335	0.5948
14.0	0.0276	0.6223
14.5	0.0199	0.6422
15.0	0.0179	0.6601
15.5	0.0158	0.6759
16.0	0.0156	0.6915
16.5	0.0154	0.7069
17.0	0.0152	0.7221
17.5	0.0150	0.7372
18.0	0.0148	0.7519
18.5	0.0145	0.7664
19.0	0.0142	0.7806
19.5	0.0139	0.7945
20.0	0.0136	0.8081
20.5	0.0133	0.8215
21.0	0.0131	0.8346
21.5	0.0130	0.8475
22.0	0.0128	0.8603
22.5	0.0126	0.8729
23.0	0.0123	0.8852
23.5	0.0120	0.8972
24.0	0.0116	0.9088
24.5	0.0112	0.9200
25.0	0.0108	0.9308
25.5	0.0104	0.9412
26.0	0.0100	0.9512
26.5	0.0096	0.9607
27.0	0.0092	0.9699
27.5	0.0086	0.9785
28.0	0.0074	0.9859
28.5	0.0054	0.9913
29.0	0.0040	0.9953
29.5	0.0030	0.9983
30.0	0.0017	1.0000

Table 4.2.8 Regional Storm Hyetograph Values for Region 4: Eastern Mountains

Note: Use the 24-hour precipitation value times 1.07 to determine the long-duration storm total precipitation amount.

Time (hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.0000	0.0000
0.5	0.0015	0.0015
1.0	0.0031	0.0046
1.5	0.0047	0.0094
2.0	0.0064	0.0158
2.5	0.0082	0.0239
3.0	0.0104	0.0343
3.5	0.0115	0.0458
4.0	0.0123	0.0581
4.5	0.0130	0.0711
5.0	0.0137	0.0848
5.5	0.0145	0.0993
6.0	0.0152	0.1145
6.5	0.0160	0.1305
7.0	0.0167	0.1472
7.5	0.0174	0.1646
8.0	0.0182	0.1828
8.5	0.0190	0.2019
9.0	0.0207	0.2226
9.5	0.0232	0.2458
10.0	0.0260	0.2717
10.5	0.0278	0.2996
11.0	0.0399	0.3394
11.5	0.0531	0.3925
12.0	0.0796	0.4722
12.5	0.0441	0.5162
13.0	0.0329	0.5492
13.5	0.0303	0.5795
14.0	0.0291	0.6086
14.5	0.0199	0.6284
15.0	0.0166	0.6451
15.5	0.0155	0.6606
16.0	0.0153	0.6759
16.5	0.0151	0.6910
17.0	0.0149	0.7059
17.5	0.0148	0.7207
18.0	0.0146	0.7353
18.5	0.0144	0.7496
19.0	0.0142	0.7639
19.5	0.0140	0.7779
20.0	0.0137	0.7915
20.5	0.0134	0.8049
21.0	0.0132	0.8181
21.5	0.0131	0.8312
22.0	0.0129	0.8441
22.5	0.0129	0.8570
23.0	0.0128	0.8697
23.5	0.0127	0.8825
24.0	0.0127	0.8951
24.5	0.0126	0.9077
25.0	0.0124	0.9201
25.5	0.0121	0.9322
26.0	0.0116	0.9438
26.5	0.0109	0.9547
27.0	0.0101	0.9647
27.5	0.0090	0.9738
28.0	0.0077	0.9814
28.5	0.0061	0.9875
29.0	0.0051	0.9926
29.5	0.0045	0.9971
30.0	0.0029	1.0000

4.2.4 Precipitation Magnitude/Frequency Analysis

The current source for precipitation magnitude-frequency estimates is NOAA Atlas II, which is based on data collected from about 1940 through 1966, and NOAA Technical Report Number 36, which used data through the late 1970s. In both of these studies, precipitation statistics were computed for each gage and used to produce point precipitation estimates at each site. The accuracy of the estimates was strongly related to the length of record at each site: estimates are generally better for common events than for rare events.

The total depth of rainfall (in tenths of an inch) for storms of 2, 5, 10, 25, 50, and 100-year recurrence intervals and 24-hour duration are published by NOAA in the form of isopluvial maps for each state. Isopluvial maps are contour maps where the contours represent total amount of rainfall. The maps for eastern Washington are shown in Figures 4.3.3 to 4.3.7; they are based on NOAA Atlas 2 maps, which are available on the Internet. The 24-hour isopluvial maps are used for designs based on the regional storm and 24-hour storms. A 2-year isopluvial map is necessary because a 6-month isopluvial map is not available. The user must scale the 2-year precipitation depth to get a 6-month precipitation depth.

An isopluvial map for the 2-year,2-hour storm is shown in Figure 4.3.2. This map is from the Dam Safety Guidelines, Technical Note 3, Design Storm Construction, Washington State Department of Ecology, Water Resources Program, report 92-55G, April 1993. It is used for sizing flow-rate-based runoff treatment BMPs with the short-duration storm.

4.2.5 Precipitation Magnitude and Frequency for 24-Hour and Regional Storms

The frequency of the water quality design storm is a 6-month recurrence interval or return period, expected to happen twice per year on the average. NOAA maps were not developed for the 6-month recurrence interval, so a conversion is necessary. Use the following equation to determine the 6-month precipitation from the 2-year,24-hour precipitation.

$$\mathbf{P_{wqs} = C_{wqs} (P_{2yr24hr})}$$

where: $\mathbf{P_{wqs}}$ = the 6-month,24-hour precipitation (inches)

$\mathbf{C_{wqs}}$ = the coefficient from Table 4.2.9 for converting the 2-year,24-hour precipitation to the 6-month,24-hour precipitation

$\mathbf{P_{2yr24hr}}$ = the 2-year,24-hour precipitation (inches), from Figure 4.3.3

P_{wqs} is used with the regional storm hyetograph or SCS Type IA or Type II hyetographs. Table 4.2.9 lists values of the coefficient C_{wqs} for the four climate regions. Table 4.2.10 provides the multipliers for converting the 24-hour precipitation P_{wqs} to the regional storm precipitation

Table 4.2.9 Values of coefficient C_{wqs} for computing 6-month, 24-hour precipitation.

Region #	Region Name	C_{wqs}
1	East Slope Cascades	0.70
2	Central Basin	0.66
3	Okanogan, Spokane, Palouse	0.69
4	NE & Blue Mountains	0.70

Note: Values of C_{wqs} are based on the Generalized Extreme Value (GEV) distribution whose distribution parameters can be expressed as a function of mean annual precipitation for eastern Washington.

Table 4.2.10 Factors for converting from 24-hour to regional storm precipitation depth

Region #	Region Name	Multiplication factor for converting from 24-hour to regional storm precipitation depth
1	East Slope Cascades	1.16
2	Central Basin	1.00
3	Okanogan, Spokane, Palouse	1.06
4	NE & Blue Mountains	1.07

4.2.6 Precipitation Magnitude and Frequency for Short-Duration Storms

Design of flow-rate-based treatment BMPs using the Single Event Hydrograph Model requires a determination of the 6-month,3-hour precipitation depth for use with the 3-hour short-duration design storm hyetograph. (The updated design storm is indexed to sum to unity at three hours, so the 3-hour precipitation depth is needed to scale the hyetograph.) Design of other BMPs or conveyance elements based on the short-duration storm may also require the conversion of the 2-year,2-hour precipitation to a 3-hour precipitation depth for a different recurrence interval.

The isopluvial map that is used as the starting point for determining the design rainfall depth for a 3-hour short-duration storm is a 2-year,2-hour precipitation isopluvial map (Figure 4.3.2).

The following equation is used to determine 3-hour precipitation for a selected return period.

$$\mathbf{P_{sds} = 1.06 * C_{sds} * P_{2yr2hr}}$$

where:

$\mathbf{P_{sds}}$ = the 3-hour precipitation (inches) for a selected return period for the short-duration storm;

1.06 = the multiplier used for **all** climatic regions to convert x-year,2-hour precipitation to x-year,3-hour precipitation;

$\mathbf{C_{sds}}$ = the coefficient (from Table 4.2.11) for converting 2-year, 2-hour precipitation to x-year,2-hour precipitation depth; and

$\mathbf{P_{2yr2hr}}$ = the 2-year,2-hour precipitation (from Figure 4.3.2).

Table 4.2.11 lists values of the coefficient C_{sds} for selected return periods for various magnitudes of mean annual precipitation. An isopluvial map of average annual precipitation is shown in Figure 4.3.1 and can be used to determine the mean annual precipitation for the site.

Table 4.2.11 Values of the coefficient C_{sds} for using 2-year,2-hour precipitation to compute 2-hour* precipitation for selected periods of return.

Region	Mean Annual Precipitation (inches)	6-Month	1-Year	10-Year	25-Year	50-Year	100-Year
2	6-8	0.61	0.79	1.63	2.17	2.68	3.29
	8-10	0.62	0.80	1.60	2.09	2.55	3.09
	10-12	0.64	0.81	1.56	2.02	2.44	2.92
2, 3	12-16	0.66	0.82	1.51	1.90	2.26	2.66
3	16-22	0.67	0.83	1.47	1.82	2.13	2.48
1, 4	22-28	0.69	0.84	1.43	1.74	2.01	2.31
	28-40	0.70	0.85	1.40	1.68	1.92	2.19
	40-60	0.72	0.86	1.36	1.61	1.82	2.05
	60-120	0.74	0.87	1.33	1.55	1.74	1.93

*2-hour precipitation is converted to 3-hour precipitation using a multiplier of 1.06 for all recurrence intervals.

Note: Values of C_{sds} are based on the Generalized Extreme Value (GEV) distribution whose distribution parameters can be expressed as a function of mean annual precipitation for eastern Washington.

4.2.7 Rain-on-Snow and Snowmelt Design

The following information on snow considerations, including rain-on-snow and snowmelt design, is optional guidance for detention and water quality design when required by the local jurisdiction. Other cold weather considerations for BMP design are included in Section 5.2.3.

Considerations for Snow

In many regions, an inevitable consequence of cold weather is precipitation in the form of snow. Table 4.2.12 illustrates some typical snowfall amounts for eastern Washington as compiled by Desert Research Institute in Nevada. While snowfall amounts are often converted to water equivalents and treated as individual events for the purpose of predicting annual precipitation events, in fact snowfall from multiple events may accumulate over time thus creating storage of potential runoff volumes. This storage may be released gradually over time in the form of snowmelt or it may be converted to runoff rapidly by rain-on-snow events. Gradual melting can cause problems because the runoff may fill or saturate stormwater BMPs prior to an actual design event and consequently produce wet soil conditions and more runoff. Refreezing during cold evenings may exacerbate some of the problems.

Table 4.2.12 Average Annual Snowfall at Selected Locations in Eastern Washington

Location	Period of Record	Average Annual Snowfall (inches)
Asotin 14 SW	1976-2000	14.5
Cle Elum	1931-2000	80.5
Dayton 1 WSW	1931-2000	17.8
Ellensburg	1901-2000	27.7
Ephrata Airport FCWOS	1949-2000	18.3
Goldendale	1931-2000	25.0
Kennewick	1948-2000	6.9
Leavenworth 3 S	1948-2000	95.2
Methow 2 S	1970-2000	38.3
Newport	1927-2000	59.4
Othello 6 ESE	1941-2000	4.2
Prosser 4 NE	1931-2000	7.9
Pullman 2 NW	1940-2000	28.1
Quincy 1 S	1941-2000	13.2
Richland	1948-2000	8.5
Spokane WSO Airport	1889-2000	41.4
Walla Walla FAA Airport	1949-1995	17.4
Wenatchee	1877-2000	27.6
Yakima WSO AP	1946-2000	24.1

Because of the many physical factors involved, snowmelt is a complicated process, with large annual variations in the melting rate frequently occurring. While the criteria presented here address the affects of rain-on-snow and snowmelt, several simplifying assumptions are made. Where local data or experiences are available, more sophisticated methods should be substituted.

Rain-on-Snow Considerations

For water quality volume, rain-on-snow events can be important in many eastern Washington regions. Although the size of rainfall events typically used in BMP design may or may not produce a significant amount of snowmelt, runoff produced by these events is high because of frozen and saturated ground conditions beneath the snow cover. The actual melting and runoff processes are quite complicated and require information not readily available in most areas. The Stormwater Practices for Cold Climates document prepared by the Center for Watershed Protection suggested the following four-step simplified procedure. As with other referenced methodology, this approach has not been well tested for eastern Washington, however it does provides a basis for estimating rain-on-snow volumes which could be used and refined with experience.

Calculating Rain-on-Snow Volume (Center for Watershed Protection):

Step 1. Many rules for sizing water quality volumes are based on treating a rainfall event with a specified occurrence frequency, such as treating the 1-year,24-hour rainfall event. The same process has been proposed for rain-on-snow events. However, rather than including all precipitation events, it is necessary to develop a data set of rainfall events that occurred only for those months where snow is on the ground. Snow events, as well as non-runoff producing events ($P < 0.1$ inch), should be excluded from this data set. The result is a recurrence frequency for rain-on-snow events. Because the ground is frozen and/or saturated, this precipitation distribution is also the same as the runoff distribution.

Step 2. Calculate a similar rainfall distribution for months without snow cover.

Step 3. Determine the runoff distribution for months without snow cover. Because we have excluded non-runoff producing events from the distribution, the runoff is equal to:

$$R = 1.0 * P * (0.05 + 0.9 I)$$

If the impervious percentage (I) is known (assume 40 %) then, for months without snow:

$$R = 0.41 * P$$

Where P is the precipitation for a return frequency computed in Step 2. A runoff distribution for "summer" is developed by multiplying all of the precipitation values used in Step 2 by the 0.41 multiplier determined previously in this step.

Step 4. Take the “winter” runoff distribution data from Step 1 and combine it with the “summer” runoff distribution computed in Step 3. Sort the data and rank it accordingly to determine an overall annual runoff distribution. Determine the 90th percentile value and use it for design purposes as long as this value is greater than the summer precipitation event.

It should again be pointed out that this methodology does not include any contribution from snowmelt. As previously stated, it is predicated on the assumption that design storm precipitation quantities are not large enough to produce significant melt quantities.

The US Army Corps of Engineers developed an expression to estimate the melt as a function of precipitation and temperature. The equation is:

$$M_s = 0.00695 * (T_{rain} - 32)\ P_r$$

This equation predicts that 2.5 inches of rainfall precipitation (P_r) at a rainfall temperature of 50 ^oF would melt 0.31 inches of snow. Whether this represents a significant increase in required volume would depend on the site.

A note concerning the impacts of snowmelt is warranted. Because the ground is generally frozen during snowmelt or rain-on-snow events, the difference between pre- and post- project discharges are often quite small. For this reason, snowmelt and rain-on-snow events rarely need to be considered when designing for channel or overbank protection.

Additional Rain-on-Snow Considerations:

Rain-on-snow could affect the flow in the evaluation of the long-duration storms, especially in regions with high snowfall. Except for higher elevations with deeper snow packs, it should be assumed that a long-duration design storm results in the complete melting and runoff of the typical snow pack. To determine the typical snow pack, calculate the average daily snow depth from December to February which is available on the Internet for many eastern Washington locations. If the average daily snow depth is less than 1 inch, then the rain-on-snow effect can be considered negligible and should not be considered in the analysis. Assuming 20 percent moisture content, determine the water equivalent. A sample of the average daily snow depths and precipitation adjustment amount for selected cities is in Table 4.2.13.

Snowmelt can also be considered in water quality design. Melting snow from the roadways and from the snow piles alongside the roadways have significant amounts of pollutants generated from the vehicles, deicers, and roadway salts. The water quality facilities should be located downstream of the snowmelt areas and can be sized for snowmelt, especially in regions with high snowfall.

Table 4.2.13 Snowmelt adjustment factors

Location	Average daily snow depth (inches)	Water equivalent (inches) 24-hour storm precipitation adjustment	24-hour : 72-hour precipitation ratio, based on climate region	Regional storm precipitation adjustment (inches)
Colville	5.00	1.0	.70	.70
Clarkston	.33	N/A	N/A	N/A
Goldendale	1.67	.33	.67	.22
Moses Lake	.67	.13	.84	.11
Omak	4.67	.93	.75	.70
Pullman	1.33	.27	.70	.19
Richland	.33	N/A	N/A	N/A
Spokane Airport	2.33	.47	.75	.35
Walla Walla	1.00	.20	.75	.15
Wenatchee	2.67	.53	.84	.45
Yakima	2.00	.40	.84	.34

For projects that are located above 2500 feet elevation, a separate study or local data should be used as the average snow depth is significant and varies widely.

The assumption is that the entire average daily snow melt on the ground will melt during the long-duration storm. Since the long-duration storm is 72 hours in duration, the water equivalent for the peak 24 hours will be less than if the long-duration storm were only 24 hours. The adjustment factor is the ratio of the 24-hour precipitation to the 72-hour precipitation and varies based on climate region. In order to utilize the snowmelt factor with the long-duration storm hyetograph, the Long-Duration Storm Precipitation Adjustment should be added to the 24-hour design storm precipitation.

The CN used shall be for normal Antecedent Moisture Condition II.

If the average annual precipitation at the project site varies from the average annual precipitation at the nearest known snow depth record location, the average daily snow depth will also vary. To determine the estimated average daily snow depth, multiply the known average daily snow depth and all other factors by the ratio of average annual precipitation at the project site to the average annual precipitation at the record location.

For example: A project is located in Cashmere where the average annual precipitation is 14 inches. The nearest snow depth record location is Wenatchee. The snow depth at Wenatchee is 2.67 inches from Table

4.2.13 and the average annual precipitation from Figure 4.3.1 is 10 inches. The estimated snow depth for Cashmere is: 2.67 * 14/10 = 3.74 inches.

Snowmelt

In relatively dry regions that receive much of their precipitation as snowfall, the sizing is heavily influenced by the snowmelt event. A typical recommendation is to oversize the facility when average annual snowfall depth is greater than or equal to annual precipitation depth. This assumes snow is approximately 10% water. The sizing criteria for the treatment of water quality are based on the following four assumptions:

1. BMPs should be sized to treat the spring snowmelt event,
2. Snowmelt runoff is influenced by the moisture content of the spring snow pack and soil moisture,
3. No more than five percent of the annual runoff volume should bypass treatment during the spring snowmelt event, and
4. Because snowmelt occurs over several days, BMPs can treat a snowmelt volume greater than their size would indicate.

Although snowmelt occurs continuously throughout the winter and spring months, the characteristics and rates of runoff may vary. As rules of thumb, 1/2 of the snowfall is assumed to melt in the winter if the average daily maximum January temperature is < 25 ^{o}F and 2/3 of the snowfall melts if the temperature is between 25 and 35 ^{o}F. Winter melting events have high concentrations of soluble pollutants such as chlorides and metals because of "preferential elution" from the snow pack (Jeffries, 1988). Conversely, spring snowmelt is higher in suspended solids and hydrophobic elements, such as hydrocarbons, which can remain in the snow pack until the last five to ten percent of water leaves the snow pack (Marsalek, 1991).

Three methods for estimating snowmelt are available, as described below.

<u>Snowmelt Method 1 (Stahre and Urbonas):</u>

Although snowmelt rates can be as high as 0.15 inches/hour (0.151 cfs/acre) under extreme conditions, Stahre and Urbonas (1989) recommended the following minimum design values:

Snowmelt = Impervious surface area x 0.04 cfs/acre + Pervious surface area x 0.02 cfs/acre

<u>Snowmelt Method 2 (US Army Corps of Engineers):</u>

The above rates from the Stahre and Urbonas method are not universally accepted. The US Army Corps of Engineers proposed the following temperature index solution for daily snowmelt (M_s) in inches per day:

$$M_s = C_m (T_{air} - T_{base})$$

Where T_{air} is the average daily air temperature (^oF), T_{base} is the base temperature (typically around 32 ^oF when using average daily air temperature), and C_m is the melt-rate coefficient in inches/ ^oF. This coefficient can be variable depending on site conditions. The relative magnitude of this factor is shown in Table 4.2.14.

Table 4.2.14 Melt Rate Coefficients for Various Conditions (assuming T_{base} = 32 ^oF)

Case	T_{air} (^oF)	Melt (inches)	C_m (inches/ ^oF)	Comment
1	70	2.57	0.068	Clear, low albedo
2	70	2.40	0.073	Case 1 2/40% forest
3	65	1.51	0.040	Case 1 w/cloud cover
4	70	1.73	0.046	Case 1 w/fresh snow
5	50	3.24	0.180	Heavy rain, windy
6	50	2.92	0.163	Light rain, windy
7	50	1.11	0.062	Light rain, light wind

Snowmelt Method 3 (Center for Watershed Protection):

The Stormwater Practices for Cold Climates document prepared by the Center for Watershed Protection presents a straightforward methodology for calculating snowmelt runoff in seven steps. The method is general and a specific application for eastern Washington has not yet been developed. However, it does provide a basis for estimation which could be used and refined as more knowledge becomes available with experience. The procedure is as follows:

Step 1. The procedure is based on the assumption that over-sizing is necessary if the average annual precipitation is less than half the average annual snowfall depth. For example, if the average annual precipitation is 15 inches and the average annual snowfall is 16 inches (or more), over-sizing will be required.

Step 2. Determine the annual losses from sublimation and snow removal.

Step 3. Determine the annual water equivalent loss from winter snowmelt events. This requires an assumption regarding the amount of water in an inch of snow. Assuming that the water equivalence of the snow is 1:10, an average annual snowfall of 40 inches, and 15 percent lost to the combination of sublimation and snow removal, the total water amount is:

$$M_s = 0.1 * (40-(0.15*40)) = 3.4 \text{ inches}$$

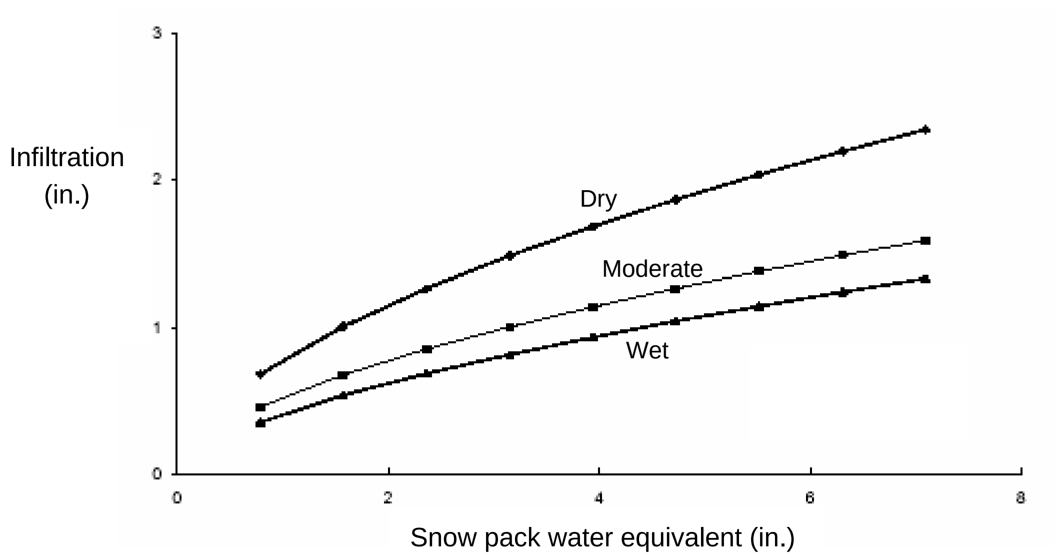
This factor is multiplied by the temperature factor (1/2 if the average daily maximum January temperature is < 25 ^{o}F and 2/3 if the temperature is between 25 and 35 ^{o}F). Assuming the average daily maximum January temperature is 24 ^{o}F, the final snow pack water equivalent (M_s) is 1.7 inches.

Step 4. Calculate the snowmelt runoff volume, R_s, using:

$$R_s = (1 - I)*(M_s - F) + (I)(M_s)$$

Where I is the impervious fraction of the watershed, F is the infiltration (inches), and Ms is the snow pack water equivalent (inches).

Figure 4.2.5 Snowmelt infiltration as a function of soil moisture



To continue the example, for moderate soil moisture conditions and 1.7 inches of snow pack water, the infiltration amount is 0.65 inches. Furthermore, if the impervious percent is 40%, then:

$$R_s = (1 - I)*(M_s - F) + (I)(M_s) = (1 - 0.4)*(1.7 - 0.65) + 0.4(1.7)$$

$$R_s = 1.31 \text{ inches}$$

Step 5. Determine the annual runoff volume. While there are several acceptable ways of computing this value, Shuler (1987) proposed a “Simple Method” whereby annual runoff (R) in inches is given by:

$$R = 0.9 * P * (0.05 + 0.9 I)$$

Assuming the annual precipitation is 15 inches/year and the impervious coefficient is still 0.4, then:

$R = 0.9 * 15 * (0.05 + 0.9 * 0.4) = 5.54$ inches

Step 6. Determine the amount of runoff to be treated (T) for a 20-acre site.

$T = (R_s – 0.05 *R) * Area /12$

$T = (1.31 – 0.05*5.54)*(50)/12 = 4.3$ acre-feet

Step 7. Because snowmelt occurs over several days or even weeks, the BMP does not have to treat the entire water quality volume over a 24-hr period. A 50 percent reduction in the volume is used to determine how much storage is required. Thus, the water quality treatment volume (WQ_v) is given by:

$WQ_v = ½ * T = 2.15$ acre-feet

Finally, this volume should be compared with the volume from precipitation considerations to determine which is more conservative.

4.3 Precipitation Maps

Precipitation maps for eastern Washington are in the following figures:

Figure 4.3.1:	Average Annual Precipitation and Climate Regions
Figure 4.3.2:	2-year,2-hour Isopluvial Map
Figure 4.3.3:	2-year,24-hour Isopluvial Map
Figure 4.3.4:	10-year,24-hour Isopluvial Map
Figure 4.3.5:	25-year,24-hour Isopluvial Map
Figure 4.3.6:	50-year,24-hour Isopluvial Map
Figure 4.3.7:	100-year,24-hour Isopluvial Map

Electronic versions of the maps are available for downloading from the Department of Ecology website; GIS coverages also can be made available for Figures 4.3.3 through 4.3.7.

4.4 Single Event Hydrograph Methods

4.4.1 Introduction

Applicability: Single Event Hydrograph Methods are the required method for designing flow control BMPs. They are an allowable method for computing peak runoff rates and runoff volumes for design of runoff treatment BMPs. Single Event Hydrograph Methods include the Soil Conservation Service (SCS) Hydrograph and the Santa Barbara Urban Hydrograph (SBUH). Commercially available computer programs for these methods may be used if the sponsor's engineer acquires acceptance from the local jurisdiction. Such acceptance shall be obtained prior to submittal of plans and calculations.

Supplemental Guidelines: The SBUH method calculates only flow that will occur from surface runoff and thus is not accurate for large drainage basins where groundwater flow can be a major contributor to the total flow. The method is most accurate for drainage basins smaller than 100 acres and should not be used for drainage basins larger than 1,000 acres.

4.4.2 Hydrograph Design Process

This section presents the general process involved in conducting a hydrologic analysis using hydrograph methods to a) design retention/detention flow control facilities and b) determine water quality treatment volumes. The exact step-by-step method for entering data into a computer model varies with the different models and is not described here. See the documentation or Help module of the computer program. Pre-developed or existing and proposed-development site runoff conditions need to be determined and documented in the Stormwater Site Plan.

<u>The process for designing retention/detention **flow control facilities** is described as follows</u>:

Review Core Element #6 in Chapter 2 to determine all flow control requirements that will apply to the proposed project.

1. Identify the climate region and average annual precipitation from Figure 4.3.1.
2. Identify two rainfall depths from Figures 4.3.3 and 4.3.5
   - 2-year,24-hour
   - 25-year (or other recurrence interval(s) required by the agency or local jurisdiction), 24-hour
3. Determine the pre-developed or existing and the proposed-development drainage basin areas, and identify pervious and impervious area (in acres) for each condition.
4. Determine soil types and hydrologic groups (A, B, C, or D) from SCS maps.

5. Determine curve numbers for pervious and impervious areas using hydrologic soil groups for both the pre-developed or existing and the proposed-development conditions; see Table 4.5.2.
6. Determine times of concentration for both pre-developed or existing and proposed-development conditions; some computer models will do these calculations if the designer enters length, slope, roughness, and flow type.
7. Select storm hyetograph and analysis time interval; verify that the analysis time interval is appropriate for use with storm hyetograph time increment.
8. Input data obtained from Steps 2, 3, 5, 6, and 7 into the computer model for both the pre-developed or existing and the proposed-development conditions.
9. Have the computer model compute the hydrographs.
10. Review the peak flow rate for the pre-developed or existing condition in the 2-year and 25-year design storms. The allowable release rate for the entire volume of the 2-year storm is 50 percent of the pre-developed or existing 2-year peak flow rate. The allowable release rate for the 25-year storm is equal to the pre-developed or existing 25-year peak flow. Note that in some cases the pre-developed or existing 2-year peak flow rate may be 0 cfs, which means there is no discharge from the site. In this situation, the 2-year proposed-development flow volume must be retained as dead storage that will ultimately infiltrate or evaporate.
11. Review the peak flow rate for the proposed-development conditions in the 2-year and 25-year storms. Compare the increases in peak flow rates for 2-year and 25-year design storms to determine if there is an increase in runoff and a flow control facility is therefore required. Also determine whether the project qualifies for applying dispersion BMPs.
12. Assume a size for the detention facility and input this size into the computer model. Most computer models will allow a vault or a pond detention facility, with or without infiltration. Refer to the volume of the design storm hydrograph computed in Step 10 for a reasonable assumption of the detention volume required.
13. Assume a size for the orifice structure and input this size into the computer model. A single orifice at the bottom of the riser may suffice in some cases. In other projects, multiple orifices may result in decreased pond sizes. For a typical pond, a reasonable approximation is 1 inch of diameter orifice per 0.05 cfs outflow. Note that the design engineer should check with the local jurisdiction to determine the minimum allowable orifice diameter.

14. Use the computer model to route the proposed-development hydrographs through the detention facility and orifice structure. Compare the proposed-development peak outflow rates to the allowable release rates identified in Step 11.
15. If the proposed-development peak outflow rates exceed the allowable release rates, adjust the detention volume, orifice size, orifice height, and(or) number of orifices. Continue iterations utilizing the computer model and adjusting the parameters until the proposed-development outflow rates are less than or equal to the allowable release rates.
16. Calculations are complete.

The process for identifying **water quality treatment** volumes or flow rates is described as follows. Note that the data required for many of the initial steps are data that are utilized in designing retention/detention flow control facilities as described above.

1. Review Core Element #5 in Chapter 2 to determine all runoff treatment requirements that will apply to the proposed project.
2. Determine the climate region and average annual precipitation from Figure 4.3.1.
3. Determine one of the following rainfall depths (depending on the type of runoff treatment BMP) from Figure 4.3.2 or 4.3.3:
   - 2-year,2-hour *for flow-rate-based treatment BMPs*
   - 2-year,24-hour *for volume-based treatment BMPs*
4. Multiply the rainfall by the appropriate coefficient to convert the 2-year to the 6-month precipitation depth:
   - $1.06*C_{sds}$ from Table 4.2.11 for 6-month,3-hour precipitation
   - C_{wqs} from Table 4.2.9 for 6-month,24-hour precipitation
5. Determine the proposed-development drainage basin areas and identify the pervious and impervious areas (in acres) that contribute flow to the treatment BMP.
6. Determine soil types and hydrologic groups (A, B, C, or D) from SCS maps.
7. Determine curve numbers for the pervious and impervious area using the hydrologic soil group for the proposed-development conditions; see Table 4.5.2
8. Determine the time of concentration for the proposed-development conditions; some computer models will do this calculation if the designer enters length, slope, roughness, and flow type.

9. If modeling the short- or long-duration storm hyetograph, select the 3-hour short-duration storm hyetographs (see Table 4.2.4) or regional long-duration storm hyetographs for the climate region (see either Table 4.2.2 or Tables 4.2.5 to 4.2.8) and analysis time interval. Check to be certain that the analysis time interval is appropriate for use with the storm hyetograph time increment.
10. Input data obtained from Steps 4, 5, 7, 8, and 9 into the computer model for the proposed-development conditions and storm event.
11. Have the computer model compute the hydrograph.
12. To design flow-rate-based treatment BMPs, use the computed peak flow from the 6-month,3-hour hydrograph .
13. To design volume-based treatment BMPs, use the computed volume from the 6-month,24-hour (or long-duration design) hydrograph.

All storm event hydrograph methods require the input of parameters that describe the physical drainage basin characteristics. These parameters provide the basis from which the runoff hydrograph is developed. The following section describes one of the three key parameters used to develop the runoff hydrograph using the SCS or SBUH method: time of concentration. The other two parameters are area and curve number, which are described in Section 4.5.

4.4.3 Travel Time and Time of Concentration

The time of concentration for rainfall shall be computed for all overland flow, ditches, channels, gutters, culverts, and pipe systems. When using the SBUH or SCS methods, the time of concentration for the various surfaces and conveyances should be computed using the following methods, which are based on the methods described in Chapter 3, NRCS publication 210-VI-TR-55, Second Ed., June 1986.

Travel time (T_t) is the time it takes water to travel from one location to another in a watershed. T_t is a component of time of concentration (T_c), which is the time for runoff to travel from the hydraulically most distant point of the watershed. T_c is computed by summing all the travel times for consecutive components of the drainage conveyance system. T_c influences the shape and peak of the runoff hydrograph. Urbanization usually decreases T_c, thereby increasing the peak discharge. But T_c can be increased as a result of (a) ponding behind small or inadequate drainage systems, including storm drain inlets and road culverts, or (b) reduction of land slope through grading.

Water moves through a watershed as sheet flow, shallow concentrated flow, open channel flow, or some combination of these. The type that occurs is best determined by field inspection.

Travel time (T_t) is the ratio of flow length to flow velocity:

$$\mathbf{T_t = L / 60\,V}$$

where: $\mathbf{T_t}$ = travel time, in minutes
L = flow length, in feet
V = average velocity, in feet per second
60 = unit conversion factor from seconds to minutes

Time of concentration (T_c) is the sum of T_t values for the various consecutive flow segments.

$$\mathbf{T_c = T_{t_1} + T_{t_2} + \ldots T_{t_m}}$$

where: $\mathbf{T_c}$ = time of concentration, in minutes
m = the number of flow segments

Sheet Flow: Sheet flow is flow over plane surfaces. It usually occurs in the headwater of streams. With sheet flow, the friction value (n_s) (a modified Manning's effective roughness coefficient that includes the effect of raindrop impact; drag over the plane surface; obstacles such as litter, crop ridges, and rocks; and erosion and transportation of sediment) is used. These n_s values are for very shallow flow depths of about 0.1 foot and are only used for travel lengths up to 300 feet. Table 4.4.1 gives Manning's n. values for sheet flow for various surface conditions.

For sheet flow up to 300 feet, use Manning's kinematic solution to directly compute T_t:

$$\mathbf{T_t = 0.42 * (n_s * L)^{0.8} / ((P_{2yr2hr})^{0.5} * (s_o)^{0.4})}$$

where: $\mathbf{T_t}$ = travel time, in minutes
$\mathbf{n_s}$ = sheet flow Manning's effective roughness coefficient from Table 4.4.1
L = flow length, in feet
$\mathbf{P_{2yr2hr}}$ = 2-year,24-hour rainfall from Figure 4.3.3, in inches ($\mathbf{P_{2yr2hr}}$ may be called $\mathbf{P_2}$ in other forms of this equation)
$\mathbf{s_o}$ = slope of hydraulic grade line or land slope, in feet per feet

Shallow Concentrated Flow: After a maximum of 300 feet, sheet flow is assumed to become shallow concentrated flow. The average velocity for this flow can be calculated using the k_s values from Table 4.4.1 in which average velocity is a function of watercourse slope and type of channel. After computing the average velocity using the Velocity Equation below, the travel time (T_t) for the shallow concentrated flow segment can be computed using the Travel Time Equation described above.

Velocity Equation: A commonly used method of computing average velocity of flow, once it has measurable depth, is the following equation:

$$V = k \sqrt{s_o}$$

where: V = velocity (ft/s)
k = time of concentration velocity factor (ft/s)
s_o = slope of flow path (ft/ft)

"k" values in Table 4.4.1 have been computed for various land covers and channel characteristics with assumptions made for hydraulic radius using the following rearrangement of Manning's equation:

$$k = (1.49\ (R)^{0.667})/n$$

where: R = an assumed hydraulic radius
n = Manning's roughness coefficient for open channel flow, from Table 4.4.1 or 4.4.2

Open Channel Flow: Open channels are assumed to begin where surveyed cross section information has been obtained, where channels are visible on aerial photographs, or where lines indicating streams appear (in blue) on United States Geological Survey (USGS) quadrangle sheets. The k_c values from Table 4.4.1 used in the Velocity Equation above or water surface profile information can be used to estimate average flow velocity. Average flow velocity is usually determined for bank-full conditions. After average velocity is computed the travel time (T_t) for the channel segment can be computed using the Travel Time Equation above.

Lakes or Wetlands: Sometimes it is necessary to estimate the velocity of flow through a lake or wetland at the outlet of a watershed. This travel time is normally very small and can be assumed as zero. Where significant attenuation may occur due to storage effects, the flows should be routed using the "level-pool routing" technique described in Section 4.6.

Limitations: The following limitations apply in estimating travel time (T_t).

- Manning's kinematic solution should not be used for sheet flow longer than 300 feet.
- In watersheds with storm sewers, carefully identify the appropriate hydraulic flow path to estimate T_c. Storm sewers generally handle only a small portion of a large event. The rest of the peak flow travels by streets, lawns, and so on, to the outlet. Consult a standard hydraulics textbook to determine average velocity in pipes for either pressure or nonpressure flow.
- A culvert or bridge can act as a reservoir outlet if there is significant storage behind it. A hydrograph should be developed to this point and the "level pool routing" technique should be used to determine the outflow rating curve through the culvert or bridge.

Table 4.4.1 Values of "n" and "k" for use in computing Time of Concentration

FOR SHEET FLOW	**n_s**
Smooth surfaces (concrete, asphalt, gravel, or bare hard soil)	0.011
Fallow fields of loose soil surface (no vegetal residue)	0.05
Cultivated soil with crop residue (slope < 0.20 ft/ft)	0.06
Cultivated soil with crop residue (slope > 0.20 ft/ft)	0.17
Short prairie grass and lawns	0.15
Dense grass	0.24
Bermuda grass	0.41
Range, natural	0.13
Woods or forest, poor cover	0.40
Woods or forest, good cover	0.80
FOR SHALLOW, CONCENTRATED FLOW	**k_s**
Forest with heavy ground litter and meadows (n = 0.10)	3
Brushy ground with some trees (n =0.06)	5
Fallow or minimum tillage cultivation (n = 0.04)	8
High grass (n = 0.035)	9
Short grass, pasture and lawns (n = 0.030)	11
Newly-bare ground (n = 0.025)	13
Paved and gravel areas (n = 0.012)	27
CHANNEL FLOW (INTERMITTENT, R = 0.2)	**k_c**
Forested swale with heavy ground litter (n=0.10)	5
Forested drainage course/ravine with defined channel bed (n=0.050)	10
Rock-lined waterway (n=0.035)	15
Grassed waterway (n=0.030)	17
Earth-lined waterway (n=0.025)	20
CMP pipe (n=0.024)	21
Concrete pipe (n=0.012)	42
Other waterways and pipes	0.508/n
CHANNEL FLOW (CONTINUOUS STREAM, R =0.4)	**k_c**
Meandering stream with some pools (n=0.040)	20
Rock-lined stream (n=0.035)	23
Grassed stream (n=0.030)	27
Other streams, man-made channels and pipe	0.807/n

Table 4.4.2 Other values of the roughness coefficient "n" for channel flow

Type of Channel and Description	Manning's "n"*	Type of Channel and Description	Manning's "n"*
A. Constructed Channels		6. Sluggish reaches, weedy	
a. Earth, straight and uniform		deep pools	0.070
1. Clean, recently completed	0.018	7. Very weedy reaches, deep	
2. Gravel, uniform selection,	0.025	pools, or floodways with	
clean		heavy stand of timber and	
3. With short grass, few	0.027	underbrush	0.100
weeds		b. Mountain streams, no vegetation	
b. Earth, winding and sluggish		in channel, banks usually steep,	
1. No vegetation	0.025	trees and brush along banks	
2. Grass, some weeds	0.030	submerged at high stages	
3. Dense weeds or aquatic		1. Bottom: gravel, cobbles and	
plants in deep channels	0.035	few boulders	0.040
4. Earth bottom and rubble		2. Bottom: cobbles with large	
sides	0.030	boulders	0.050
5. Stony bottom and weedy		B-2 Flood plains	
banks	0.035	a. Pasture, no brush	
6. Cobble bottom and clean		1. Short grass	0.030
sides	0.040	2. High grass	0.035
c. Rock lined		b. Cultivated areas	
1. Smooth and uniform	0.035	1. No crop	0.030
2. Jagged and irregular	0.040	2. Mature row crops	0.035
d. Channels not maintained,		3. Mature field crops	0.040
weeds and brush uncut		c. Brush	
1. Dense weeds, high as flow		1. Scattered brush, heavy	
depth	0.080	weeds	0.050
2. Clean bottom, brush on		2. Light brush and trees	0.060
sides	0.050	3. Medium to dense brush	0.070
3. Same, highest stage of		4. Heavy, dense brush	0.100
flow	0.070	d. Trees	
4. Dense brush, high stage	0.100	1. Dense willows, straight	0.150
B. Natural Streams		2. Cleared land with tree	
B-1 Minor streams (top width		stumps, no sprouts	0.040
at flood stage < 100ft.)		3. Same as above, but with	
a. Streams on plain		heavy growth of sprouts	0.060
1. Clean, straight, full stage		4. Heavy stand of timber, a few	
no rifts or deep pools	0.030	down trees, little	
2. Same as above, but more		undergrowth, flood stage	
stones and weeds	0.035	below branches	0.100
3. Clean, winding, some		5. Same as above, but with	
pools and shoals	0.040	flood stage reaching	
4. Same as above, but some		branches	0.120
Weeds	0.040		
5. Same as 4, but more			
Stones	0.050		

*Note, these "n" values are "normal" values for use in analysis of channels. For conservative design for channel capacity the "maximum" values listed in other references should be considered. For channel bank stability the minimum values should be considered.

Example: The following is an example of travel time and time of concentration calculations.

Given: An existing drainage basin having a selected flow route composed of the following 4 segments: (Note: Drainage basin has a P_2 = 0.8 inches.)

Segment 1: L = 200 ft, Forest with good cover (sheet flow)
s_o = 0.03 ft/ft, n_s = 0.80
Segment 2: L = 300 ft, Pasture (shallow concentrated flow)
s_o = 0.04 ft/ft, k_s = 11
Segment 3: L = 300 ft, Grassed waterway (intermittent channel)
s_o = 0.05, k_c = 17
Segment 4: L = 500 ft, Grass-lined stream (continuous)
s_o = 0.02, k_c = 27

Calculate travel times (T_t) for each reach and then sum them to calculate the drainage basin time of concentration (T_c).

Segment 1: Sheet flow, (L < 300 feet)

$$T_t = \frac{0.42(n_s L)^{0.8}}{(P_2)^{0.5}(s_o)^{0.4}}$$

$$T_1 = \frac{(0.42)[(0.80)(200)]^{0.8}}{(0.8)^{0.3}(0.03)^{0.4}} = \underline{106\,\text{minutes}}$$

Segment 2: Shallow concentrated flow

$$V = k_s \sqrt{s_o}$$

$$V_2 = (11)\sqrt{(0.04)} = 2.2\,\text{ft/s}$$

$$T_2 = \frac{L}{60\,V} = \frac{(300)}{60(2.2)} = \underline{2\,\text{minutes}}$$

Segment 3: Intermittent channel flow

$$V_4 = (17)\sqrt{(0.05)} = 3.8\,\text{ft/s}$$

$$T_4 = \frac{(300)}{60(3.8)} = \underline{1\,\text{minute}}$$

Segment 4: Continuous stream

$$V_5 = (27)\sqrt{(0.02)} = 3.8\,\text{ft/s}$$

$$T_5 = \frac{(500)}{60(3.8)} = \underline{2\,\text{minutes}}$$

$T_c = T_1 + T_2 + T_3 + T_4$

T_c = 106 + 2 + 1 + 2 = $\underline{111\text{ minutes}}$

It is important to note how the initial sheet flow segment's travel time dominates the time of concentration computation. This will nearly always be the case for relatively small drainage basins and in particular for the existing site conditions. This also illustrates the significant impact urbanization has on the surface runoff portion of the hydrologic process.

The time of concentration should be calculated for each significantly different slope. Travel time for flow in pipes, ditches and gutters should be computed as a function of the velocity as defined by the Manning formula.

4.4.4 Hydrograph Synthesis

This section presents a description of the Santa Barbara Urban Hydrograph (SBUH) method. This method is used to synthesize the runoff hydrograph from precipitation excess (time distribution of runoff) and time of concentration.

The SBUH method was developed by the Santa Barbara County Flood Control and Water Conservation District, California. The SBUH method directly computes a runoff hydrograph without going through an intermediate process (unit hydrograph) as the SCSUH method does. By comparison, the calculation steps of the SBUH method are much simpler and can be programmed on a calculator or a spreadsheet program. Commercial software is also available that can perform these calculations.

The SBUH method uses two steps to synthesize the runoff hydrograph:

Step 1: Compute the instantaneous hydrograph, and

Step 2: Compute the runoff hydrograph.

The instantaneous hydrograph is computed as follows:

$$l(t) = 60.5\ R(t)\ A/dt$$

where: $l(t)$ = the instantaneous hydrograph at each time step dt, in cubic feet per second

$R(t)$ = total runoff depth from both impervious and pervious runoffs at time increment dt, in inches. This is also known as precipitation excess.

A = area, in acres

dt = time interval, in minutes. Note: A maximum time interval of 5 minutes is used for all short-duration design storms. A maximum time interval of 30 minutes is used for all regional design storms.

The runoff hydrograph is then obtained by routing the instantaneous hydrograph through an imaginary reservoir with a time delay equal to the time of concentration of the drainage basin. The following equation estimates the routed flow:

$$Q(t+1) = Q(t) + w[I(t) + I(t+1) - 2Q(t)]$$

where: $Q(t)$ = the runoff hydrograph or routed flow, in cfs
$w = dt/(2T_c + dt)$, where T_c is the time of concentration
dt = time interval, in minutes

Example: To illustrate the SBUH method, Figure 4.4.1 shows a runoff hydrograph computed by this method. These examples were prepared using spreadsheet program. These examples illustrate how the method can be performed with a personal computer. In order to save space, time increments with all values equal to zero have been omitted.

Figure 4.4.1 Example SBUH Runoff Hydrograph

Existing Site Condition
REGION 2, 25-YEAR REGIONAL STORM

Given			
Area (ac.) = **5.0**	P_t (inches) = **1.6**	d_t (min.)= **30**	T_c (min)= **40**
w =routing constant $=d_t/(2T_c + d_t)$ = **0.2727**			
Pervious Area (ac.): Area = **5.0**	CN = **65**	S = (1000/CN) -10 = **5.38**	0.2S = **1.08**
Impervious Area (ac.): Area = **0.0**	CN = **98**	S = (1000/CN) -10 = **0.20**	0.2S = **0.04**

Column (3) = rainfall distribution
Column (4) = Column (3) x P_t
Column (5) = P = Accumulated sum of Column (4)
Column (6) = (If P ≤ 0.2S)= 0; (If P > 0.2S)= [(Column (5) – 0.2)^2/(Column (5) + 0.8S)] where PERVIOUS AREA S value is used
Column (7) = Column (6) of present step – Column (6) of previous step
Column (8) = (If P ≤ 0.2S)= 0; (If P > 0.2S)= [(Column (5) – 0.2)^2/(Column (5) + 0.8S)] where IMPERVIOUS AREA S value is used
Column (9) = Column (8) of present step – Column (8) of previous step
Column (10) = [(PERVIOUS AREA/TOTAL AREA) * Column (7)] + [(IMPERVIOUS AREA/TOTAL AREA) x Column (9)]
Column (11) = (60.5 x Column (10) x TOTAL AREA)/d_t
Column (12) = Column (12) of previous time + w[(Column (11) of previous time step + Column (11) of present time step) – (2 x Column (12) of previous time step)] where $w = d_t /(2T_c + d_t)$

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
					Pervious Area		Impervious Area				
Time Incr.	Time (min)	Rainfall Distrib. (fraction)	Incre. Rainfall (inches)	Accumul. Rainfall (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
1	0	0.00000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.00
2	30	0.00000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.00
3	60	0.00000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.00
…											
90	2670	0.06220	0.100	0.934	0.000	0.000	0.495	0.089	0.000	0.0	0.00
91	2700	0.09330	0.149	1.083	0.000	0.000	0.632	0.137	0.000	0.0	0.00
92	2730	0.05275	0.084	1.167	0.001	0.001	0.711	0.079	0.001	0.0	0.00
93	2760	0.04025	0.064	1.232	0.004	0.003	0.772	0.061	0.003	0.0	0.01
94	2790	0.03717	0.059	1.291	0.008	0.004	0.828	0.056	0.004	0.0	0.02
95	2820	0.03483	0.056	1.347	0.013	0.005	0.881	0.053	0.005	0.0	0.03
96	2850	0.03307	0.053	1.400	0.018	0.005	0.931	0.051	0.005	0.1	0.04
97	2880	0.02893	0.046	1.446	0.024	0.005	0.976	0.044	0.005	0.1	0.05

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
					Pervious Area		Impervious Area				
Time Incr.	Time (min)	Rainfall Distrib. (fraction)	Incre. Rainfall (inches)	Accumul. Rainfall (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
98	2910	0.02519	0.040	1.486	0.029	0.005	1.015	0.039	0.005	0.1	0.05
99	2940	0.02189	0.035	1.521	0.034	0.005	1.048	0.034	0.005	0.0	0.05
100	2970	0.01906	0.030	1.552	0.039	0.005	1.078	0.029	0.005	0.0	0.05
101	3000	0.01670	0.027	1.579	0.043	0.004	1.103	0.026	0.004	0.0	0.05
102	3030	0.01480	0.024	1.602	0.047	0.004	1.126	0.023	0.004	0.0	0.04
103	3060	0.01336	0.021	1.624	0.050	0.004	1.147	0.021	0.004	0.0	0.04
104	3090	0.01234	0.020	1.643	0.054	0.004	1.166	0.019	0.004	0.0	0.04
105	3120	0.01156	0.018	1.662	0.057	0.003	1.184	0.018	0.003	0.0	0.04
106	3150	0.01096	0.018	1.679	0.061	0.003	1.201	0.017	0.003	0.0	0.04
107	3180	0.01054	0.017	1.696	0.064	0.003	1.217	0.016	0.003	0.0	0.03
108	3210	0.01032	0.017	1.713	0.067	0.003	1.233	0.016	0.003	0.0	0.03
109	3240	0.01028	0.016	1.729	0.070	0.003	1.249	0.016	0.003	0.0	0.03
110	3270	0.01038	0.017	1.746	0.074	0.003	1.265	0.016	0.003	0.0	0.03
111	3300	0.01046	0.017	1.763	0.077	0.004	1.282	0.016	0.004	0.0	0.03
112	3330	0.01046	0.017	1.779	0.081	0.004	1.298	0.016	0.004	0.0	0.04
113	3360	0.01040	0.017	1.796	0.085	0.004	1.314	0.016	0.004	0.0	0.04
114	3390	0.01025	0.016	1.812	0.088	0.004	1.330	0.016	0.004	0.0	0.04
115	3420	0.01004	0.016	1.828	0.092	0.004	1.346	0.016	0.004	0.0	0.04
116	3450	0.00974	0.016	1.844	0.096	0.004	1.361	0.015	0.004	0.0	0.04
117	3480	0.00926	0.015	1.859	0.099	0.003	1.375	0.014	0.003	0.0	0.04
118	3510	0.00868	0.014	1.873	0.102	0.003	1.389	0.014	0.003	0.0	0.04
119	3540	0.00832	0.013	1.886	0.106	0.003	1.402	0.013	0.003	0.0	0.03
120	3570	0.00781	0.012	1.899	0.109	0.003	1.414	0.012	0.003	0.0	0.03
121	3600	0.00500	0.008	1.907	0.111	0.002	1.422	0.008	0.002	0.0	0.03
122	3630	0.00000	0.000	1.907	0.111	0.000	1.422	0.000	0.000	0.0	0.02
123	3660	0.00000	0.000	1.907	0.111	0.000	1.422	0.000	0.000	0.0	0.01
124	3690	0.00000	0.000	1.907	0.111	0.000	1.422	0.000	0.000	0.0	0.00
125	3720	0.00000	0.000	1.907	0.111	0.000	1.422	0.000	0.000	0.0	0.00
…											
145	4320	0.00000	0.000	1.907	0.111	0.000	1.422	0.000	0.000	0.0	0.00

Figure 4.4.1 (continued) Example SBUH Runoff Hydrograph

Proposed Development Site Condition
REGION 2, 25-YEAR REGIONAL STORM

Given			
Area (ac.) = **5.0**	P_t (inches) = **1.6**	d_t (min.)= **30**	T_c (min)= **5**
w =routing constant =$d_t/(2T_c + d_t)$ = **0.750**			
Pervious Area (ac.): Area = **0.5**	CN = **65**	S = (1000/CN) -10 = **5.38**	0.2S = **1.08**
Impervious Area (ac.): Area = **4.5**	CN = **98**	S = (1000/CN) -10 = **0.20**	0.2S = **0.04**

Column (3) = rainfall distribution
Column (4) = Column (3) x P_t
Column (5) = P = Accumulated sum of Column (4)
Column (6) = (If P ≤ 0.2S)= 0; (If P > 0.2S)= [(Column (5) – 0.2)^2/(Column (5) + 0.8S)] where PERVIOUS AREA S value is used
Column (7) = Column (6) of present step – Column (6) of previous step
Column (8) = (If P ≤ 0.2S)= 0; (If P > 0.2S)= [(Column (5) – 0.2)^2/(Column (5) + 0.8S)] where IMPERVIOUS AREA S value is used
Column (9) = Column (8) of present step – Column (8) of previous step
Column (10) = [(PERVIOUS AREA/TOTAL AREA) * Column (7)] + [(IMPERVIOUS AREA/TOTAL AREA) x Column (9)]
Column (11) = (60.5 x Column (10) x TOTAL AREA)/d_t
Column (12) = Column (12) of previous time + w[(Column (11) of previous time step + Column (11) of present time step) – (2 x Column (12) of previous time step)] where w = d_t /($2T_c$+ d_t)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
					Pervious Area		Impervious Area				
Time Incr.	Time (min)	Rainfall Distrib. (fraction)	Incre. Rainfall (inches)	Accum. Rainfall (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
1	0	0.00000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.00
2	30	0.00000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.00
3	60	0.00000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.00
…											
22	630	0.01669	0.027	0.046	0.000	0.000	0.000	0.000	0.000	0.0	0.00
23	660	0.02831	0.045	0.092	0.000	0.000	0.010	0.010	0.009	0.1	0.07
24	690	0.04680	0.075	0.167	0.000	0.000	0.048	0.038	0.034	0.3	0.29
25	720	0.03120	0.050	0.217	0.000	0.000	0.081	0.033	0.030	0.3	0.34
26	750	0.02549	0.041	0.257	0.000	0.000	0.111	0.030	0.027	0.3	0.26
27	780	0.01451	0.023	0.281	0.000	0.000	0.129	0.018	0.016	0.2	0.20
28	810	0.00445	0.007	0.288	0.000	0.000	0.135	0.006	0.005	0.1	0.06
29	840	0.00202	0.003	0.291	0.000	0.000	0.138	0.003	0.002	0.0	0.02

(1)	(2)	(3)	(4)	(5)	(6) Pervious Area	(7) Pervious Area	(8) Impervious Area	(9) Impervious Area	(10)	(11)	(12)
Time Incr.	Time (min)	Rainfall Distrib. (fraction)	Incre. Rainfall (inches)	Accum. Rainfall (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
30	870	0.00192	0.003	0.294	0.000	0.000	0.140	0.002	0.002	0.0	0.02
31	900	0.00172	0.003	0.297	0.000	0.000	0.142	0.002	0.002	0.0	0.02
32	930	0.00152	0.002	0.299	0.000	0.000	0.144	0.002	0.002	0.0	0.02
33	960	0.00132	0.002	0.301	0.000	0.000	0.146	0.002	0.002	0.0	0.02
34	990	0.00112	0.002	0.303	0.000	0.000	0.147	0.001	0.001	0.0	0.01
35	1020	0.00092	0.001	0.305	0.000	0.000	0.149	0.001	0.001	0.0	0.01
36	1050	0.00072	0.001	0.306	0.000	0.000	0.150	0.001	0.001	0.0	0.01
37	1080	0.00052	0.001	0.307	0.000	0.000	0.150	0.001	0.001	0.0	0.01
38	1110	0.00000	0.000	0.307	0.000	0.000	0.150	0.000	0.000	0.0	0.00
39	1140	0.00000	0.000	0.307	0.000	0.000	0.150	0.000	0.000	0.0	0.00
…											
72	2130	0.00000	0.000	0.307	0.000	0.000	0.150	0.000	0.000	0.0	0.00
73	2160	0.00000	0.000	0.307	0.000	0.000	0.150	0.000	0.000	0.0	0.00
74	2190	0.00544	0.009	0.315	0.000	0.000	0.157	0.007	0.006	0.1	0.05
75	2220	0.00856	0.014	0.329	0.000	0.000	0.169	0.011	0.010	0.1	0.10
76	2250	0.01000	0.016	0.345	0.000	0.000	0.182	0.013	0.012	0.1	0.12
77	2280	0.01200	0.019	0.364	0.000	0.000	0.198	0.016	0.015	0.1	0.14
78	2310	0.01300	0.021	0.385	0.000	0.000	0.216	0.018	0.016	0.2	0.16
79	2340	0.01400	0.022	0.407	0.000	0.000	0.235	0.019	0.017	0.2	0.17
80	2370	0.01500	0.024	0.431	0.000	0.000	0.256	0.021	0.019	0.2	0.19
81	2400	0.01600	0.026	0.457	0.000	0.000	0.279	0.023	0.020	0.2	0.20
82	2430	0.01700	0.027	0.484	0.000	0.000	0.304	0.024	0.022	0.2	0.22
83	2460	0.01869	0.030	0.514	0.000	0.000	0.331	0.027	0.024	0.2	0.24
84	2490	0.02281	0.036	0.551	0.000	0.000	0.364	0.033	0.030	0.3	0.29
85	2520	0.02832	0.045	0.596	0.000	0.000	0.406	0.042	0.038	0.4	0.37
86	2550	0.03050	0.049	0.645	0.000	0.000	0.451	0.045	0.041	0.4	0.41
87	2580	0.03350	0.054	0.698	0.000	0.000	0.502	0.050	0.045	0.5	0.45
88	2610	0.03650	0.058	0.757	0.000	0.000	0.557	0.055	0.050	0.5	0.50
89	2640	0.04842	0.077	0.834	0.000	0.000	0.631	0.074	0.067	0.7	0.63
90	2670	0.06220	0.100	0.934	0.000	0.000	0.727	0.096	0.086	0.9	0.84
91	2700	0.09330	0.149	1.083	0.000	0.000	0.871	0.145	0.130	1.3	1.22
92	2730	0.05275	0.084	1.167	0.001	0.001	0.954	0.082	0.074	0.7	0.94
93	2760	0.04025	0.064	1.232	0.004	0.003	1.017	0.063	0.057	0.6	0.52
94	2790	0.03717	0.059	1.291	0.008	0.004	1.075	0.058	0.053	0.5	0.57
95	2820	0.03483	0.056	1.347	0.013	0.005	1.130	0.055	0.050	0.5	0.49
96	2850	0.03307	0.053	1.400	0.018	0.005	1.182	0.052	0.047	0.5	0.49
97	2880	0.02893	0.046	1.446	0.024	0.005	1.227	0.046	0.042	0.4	0.43
98	2910	0.02519	0.040	1.486	0.029	0.005	1.267	0.040	0.036	0.4	0.37
99	2940	0.02189	0.035	1.521	0.034	0.005	1.301	0.034	0.032	0.3	0.33
100	2970	0.01906	0.030	1.552	0.039	0.005	1.331	0.030	0.028	0.3	0.28

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
					Pervious Area		Impervious Area				
Time Incr.	Time (min)	Rainfall Distrib. (fraction)	Incre. Rainfall (inches)	Accum. Rainfall (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Accum. Runoff (inches)	Incre. Runoff (inches)	Total Runoff (inches)	Instant Flowrate (cfs)	Design Flowrate (cfs)
101	3000	0.01670	0.027	1.579	0.043	0.004	1.358	0.026	0.024	0.2	0.25
102	3030	0.01480	0.024	1.602	0.047	0.004	1.381	0.023	0.021	0.2	0.22
103	3060	0.01336	0.021	1.624	0.050	0.004	1.402	0.021	0.019	0.2	0.20
104	3090	0.01234	0.020	1.643	0.054	0.004	1.422	0.019	0.018	0.2	0.18
105	3120	0.01156	0.018	1.662	0.057	0.003	1.440	0.018	0.017	0.2	0.17
106	3150	0.01096	0.018	1.679	0.061	0.003	1.457	0.017	0.016	0.2	0.16
107	3180	0.01054	0.017	1.696	0.064	0.003	1.474	0.017	0.015	0.2	0.16
108	3210	0.01032	0.017	1.713	0.067	0.003	1.490	0.016	0.015	0.2	0.15
109	3240	0.01028	0.016	1.729	0.070	0.003	1.506	0.016	0.015	0.2	0.15
110	3270	0.01038	0.017	1.746	0.074	0.003	1.523	0.016	0.015	0.2	0.15
111	3300	0.01046	0.017	1.763	0.077	0.004	1.539	0.017	0.015	0.2	0.15
112	3330	0.01046	0.017	1.779	0.081	0.004	1.556	0.017	0.015	0.2	0.15
113	3360	0.01040	0.017	1.796	0.085	0.004	1.572	0.016	0.015	0.2	0.15
114	3390	0.01025	0.016	1.812	0.088	0.004	1.589	0.016	0.015	0.2	0.15
115	3420	0.01004	0.016	1.828	0.092	0.004	1.604	0.016	0.015	0.1	0.15
116	3450	0.00974	0.016	1.844	0.096	0.004	1.620	0.015	0.014	0.1	0.14
117	3480	0.00926	0.015	1.859	0.099	0.003	1.635	0.015	0.014	0.1	0.14
118	3510	0.00868	0.014	1.873	0.102	0.003	1.648	0.014	0.013	0.1	0.13
119	3540	0.00832	0.013	1.886	0.106	0.003	1.662	0.013	0.012	0.1	0.12
120	3570	0.00781	0.012	1.899	0.109	0.003	1.674	0.012	0.011	0.1	0.12
121	3600	0.00500	0.008	1.907	0.111	0.002	1.682	0.008	0.007	0.1	0.08
122	3630	0.00000	0.000	1.907	0.111	0.000	1.682	0.000	0.000	0.0	0.01
123	3660	0.00000	0.000	1.907	0.111	0.000	1.682	0.000	0.000	0.0	0.00
124	3690	0.00000	0.000	1.907	0.111	0.000	1.682	0.000	0.000	0.0	0.00
…											
144	4290	0.00000	0.000	1.907	0.111	0.000	1.682	0.000	0.000	0.0	0.00
145	4320	0.00000	0.000	1.907	0.111	0.000	1.682	0.000	0.000	0.0	0.00

4.5 SCS Curve Number Equations

4.5.1 Introduction

Applicability: The SCS Curve Number equation is an allowable method for computing storage volumes for volume based treatment BMPs based on the SCS hydrograph method. The SCS curve numbers are also used in the Single Event Hydrograph Methods such as SCS Hydrograph and Santa Barbara Urban Hydrograph.

The primary source for this section is the Surface Water Management Manual for Western Washington, by Dept. of Ecology, 2001 and Urban Hydrology for Small Watersheds TR-55, by Natural Resources Conservation Service, 1986.

This method can be used to size the volume of treatment BMPs when the design is based on the volume of runoff. Computer models are not required for this method. Required input consists of precipitation, pervious and impervious area and curve numbers.

4.5.2 Area

Drainage sub-basin areas should be delineated in a manner that runoff characteristics are as homogeneous as practicable and in reasonable configurations. Sub-basin configurations should be contiguous and consistent with surface runoff patterns. Refer to 4.5.3 Curve Number for discussion regarding when weighted averaging is appropriate and not appropriate.

4.5.3 Curve Number

The Natural Resources Conservation Service (NRCS, formerly the Soil Conservation Service) has for many years conducted studies into the runoff characteristics of various land types. After gathering and analyzing extensive data, the NRCS has developed relationships between land use, soil type, vegetation cover, interception, infiltration, surface storage, and runoff. These relationships have been characterized by a single runoff coefficient called a "curve number" (CN). The National Engineering Handbook - Section 4: Hydrology (NEH-4, SCS, 1985) contains a detailed description of the development and use of the curve number method. The CN indicates the runoff potential of a watershed. Higher CNs have a higher potential for runoff. The CN is a combination of a hydrologic soil group, a land use, and a treatment class (cover).

NRCS is considering revisions to the curve numbers but, at the time of this writing, has not completed that effort. When revised curve numbers are adopted by NRCS they should be considered for use in lieu of the values published herein.

The combination of soil type and land use is called the "soil-cover complex." The soil-cover complexes have been assigned to one of four hydrologic soil groups, according to their runoff characteristics. SCS has classified over 4,000 soil types into these four soil groups. Table 4.5.1 shows the hydrologic soil group of some of the common soils in eastern Washington and provides a brief description of the four hydrologic soil group classifications. For details on the hydrologic soil group for other soil types refer to the SCS maps published for each county.

Table 4.5.1 Hydrologic Soil Groups of Selected Soils in Eastern Washington. See SCS Soils Maps for additional soil and hydrologic groups

Soil Group	Hydrologic Group	Soil Group	Hydrologic Group
Athena	B	Laketon	C
Bernhill	B	Lance	B
Bong	A	Larkin	B
Bonner	B	Latah	D
Brickel	C	Marble	A
Bridgeson	D	Mondovi	B
Caldwell	C	Moscow	C
Cedonia	B	Naff	B
Cheney	B	Narcisse	C
Clayton	B	Nez Perce	C
Cocolalla	D	Palouse	B
Dearyton	C	Peone	D
Dragoon	C	Phoebe	B
Eloika	B	Reardan	C
Emdent	D	Schumacher	B
Freeman	C	Semiahmoo	D
Garfield	C	Snow	B
Garrison	B	Speigle	B
Glenrose	B	Spokane	C
Green Bluff	B	Springdale	A
Hagen	B	Tekoa	C
Hardesty	B	Uhlig	B
Hesseltine	B	Vassar	B
Konner	D	Wethey	C
Lakesol	B	Wolfeson	C

Source: U.S. Soil Conservation Service: TR-55, Second Edition, June 1986, Appendix A.

Hydrologic Soil Group Classifications

A. Low runoff potential: Soils having high infiltration rates, even when thoroughly wetted, and consisting chiefly of deep, well-to-excessively drained sands or gravels. These soils have a high rate of water transmission.

B. Moderately low runoff potential: Soils having moderate infiltration rates when thoroughly wetted, and consisting chiefly of moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

C. Moderately high runoff potential: Soils have slow infiltration rates when thoroughly wetted, and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine textures. These soils have a slow rate of water transmission.

D. High runoff potential: Soils having very slow infiltration rates when thoroughly wetted, and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a hardpan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

The following are important criteria/considerations for selection of CN values:

Many factors may affect the CN value for a given land use. For example, the movement of heavy equipment over bare ground may compact the soil so that it has a lesser infiltration rate and greater runoff potential than would be indicated by strict application of the CN value based on predevelopment conditions at the site.

Separate CN values must be selected for the pervious and impervious areas of an urban basin or sub-basin. For all developed areas, the percent impervious must be estimated from best available plans, topography, or aerial photography and verified by field reconnaissance. Generally, the pervious area CN value shall be a weighted average of all the pervious area CN values within the sub-basin. However, if two large homogeneous areas (such as a parking lot and a park) within the same sub-basin have CN values which differ by more than 20 points, separate hydrographs need to be generated for the two areas and the hydrographs then summed. See the example provided later in this section.

Directly connected impervious areas are areas such as roofs and driveways from which runoff directly enters the drainage system without first traversing an area of pervious ground. Unconnected impervious areas are areas whose runoff is spread over a pervious area as sheet flow and include such items as a tennis court in the middle of a lawn. Unconnected impervious areas can be weighted with pervious areas.

Table 4.5.2 gives CNs for agricultural, suburban, and urban land use classifications. These Curve Number values listed in Table 4.5.2 are applicable under normal antecedent moisture conditions (AMC II) and are the basis of design in eastern Washington.

High groundwater or shallow bedrock can cause a significant increase in runoff. If either of these conditions exists, it needs to be addressed by the design engineer. For a more complete discussion of computing weighted CN values, see NRCS publication 210-VI-TR-55, Second Edition, June 1986.

Table 4.5.2 Runoff Curve Numbers (CNs) for selected agricultural, suburban, and urban areas

	CNs for hydrologic soil group			
Cover type and hydrologic condition	A	B	C	D
Open space (lawns, parks, golf courses, cemeteries, landscaping, etc.)[1]				
Poor condition (grass cover <50% of the area)	68	79	86	89
Fair condition (grass cover on 50% to 75% of the area)	49	69	79	84
Good condition (grass cover on >75% of the area)	39	61	74	80
Impervious areas:				
Open water bodies: lakes, wetlands, ponds etc.	100	100	100	100
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)	98	98	98	98
Porous pavers and permeable interlocking concrete (assumed as 85% impervious and 15% lawn)				
Fair lawn condition (weighted average CNs)	95	96	97	97
Gravel (including right-of-way)	76	85	89	91
Dirt (including right-of-way)	72	82	87	89
Pasture, grassland, or range-continuous forage for grazing				
Poor condition (ground cover <50% or heavily grazed with no mulch).	68	79	86	89
Fair condition (ground cover 50% to 75% and not heavily grazed)	49	69	79	84
Good condition (ground cover >75% and lightly or only occasionally grazed)	39	61	74	80
Cultivated agricultural lands				
Row Crops (good) e.g., corn, sugar beets, soy beans	64	75	82	85
Small Grain (good) e.g., wheat, barley, flax	60	72	80	84
Meadow (continuous grass, protected from grazing and generally mowed for hay)	30	58	71	78
Brush (brush-weed-grass mixture with brush the major element)				
Poor (<50% ground cover)	48	67	77	83
Fair (50% to 75% ground cover)	35	56	70	77
Good (>75% ground cover)	30[2]	48	65	73
Woods-grass combination (orchard or tree farm)[3]				
Poor	57	73	82	86
Fair	43	65	76	82
Good	32	58	72	79
Woods				
Poor (Forest litter, small trees, and brush destroyed by heavy grazing or regular burning	45	66	77	83
Fair (Woods are grazed but not burned, and some forest litter covers the soil)	36	60	73	79
Good (Woods are protected from grazing, and litter and brush adequately cover the soil)	30	55	70	77
Herbaceous (mixture of grass, weeds, and low-growing brush, with brush the minor element)[4]				
Poor (<30% ground cover)		80	87	93
Fair (30% to 70% ground cover)		71	81	89
Good (>70% ground cover)		62	74	85
Sagebrush with grass understory[4]				
Poor (<30% ground cover)		67	80	85
Fair (30% to 70% ground cover)		51	63	70
Good (>70% ground cover)		35	47	55
For a more detailed and complete description of land use curve numbers refer to chapter two (2) of the Soil Conservation Service's Technical Release No. 55 , (210-VI-TR-55, Second Ed., June 1986).				

[1] Composite CNs may be computed for other combinations of open space cover type.

[2] Actual curve number is less than 30; use CN = 30 for runoff computations.

[3] CNs shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CNs for woods and pasture.

[4] Curve numbers have not been developed for group A soils.

Table 4.5.3 Curve Number conversions for Antecedent Moisture Conditions (Case Ia = 0.2 S)

CN for AMC II	CN for AMC I	CN for AMC III	CN for AMC II	CN for AMC I	CN for AMC III
100	100	100	76	58	89
99	97	100	75	57	88
98	94	99	74	55	88
97	91	99	73	54	87
96	89	99	72	53	86
95	87	98	71	52	86
94	85	98	70	51	85
93	83	98	69	50	84
92	81	97	68	48	84
91	80	97	67	47	83
90	78	96	66	46	82
89	76	96	65	45	82
88	75	95	64	44	81
87	73	95	63	43	80
86	72	94	62	42	79
85	70	94	61	41	78
84	68	93	60	40	78
83	67	93	59	39	78
82	66	92	58	38	76
81	64	92	57	37	75
80	63	91	56	36	75
79	62	91	55	35	74
78	60	90	54	34	73
77	59	89	50	31	70

Source: SCS-NEH4. Table 10.1.

Antecedent Moisture Condition: The moisture condition in a soil at the onset of a storm event, referred to as the antecedent moisture condition (AMC), has a significant effect on both the volume and rate of runoff. Recognizing that fact, the SCS developed three antecedent soil moisture conditions that are labeled conditions I, II, and III. The description of each condition is:

AMC I: soils are dry but not to wilting point

AMC II: average conditions

AMC III: heavy rainfall, or light rainfall and low temperatures have occurred within the last 5 days; near saturated or saturated soil

Table 4.5.4 gives seasonal rainfall limits for the three antecedent soil moisture conditions.

Table 4.5.4 Total 5-day antecedent rainfall (inches)

AMC	Dormant Season	Growing Season
I	Less than 0.5	Less than 1.4
II	0.5 to 1.1	1.4 to 2.1
III	Over 1.1	Over 2.1

Varying antecedent moisture conditions are used in the design of evaporation ponds in Section 6.4. See Table 4.5.3 for the curve number conversions for different antecedent moisture conditions for the case of Ia = 0.2S. For other conversion, see the SCS National Engineering Handbook No. 4, 1985.

Supplemental Guidelines: Local jurisdictions may wish to restrict the curve numbers used to describe the pre-developed or existing condition and generate the runoff in the proposed development condition. The lower curve numbers result in lower runoff and mitigate for past changes to the natural drainage patterns. Restricting the allowable curve numbers can also reduce the subjectivity that is inherent in the selection of curve numbers.

Example: The following is an example of how CN values are selected for a sample project.

Select CNs for the following development:

Existing land use: woods (thin stand, poor cover)

Future land use: 80% impervious

Basin size: 10 acres

Soil type: 80% Garfield, 20% Bonner, split between the pervious and impervious areas.

Table 4.5.1 shows that Garfield soil belongs to the "C" hydrologic soil group and Bonner soil belongs to the "B" group. Therefore, for the existing condition, CNs of 77 and 66 are read from Table 4.5.2 and area weighted to obtain a CN value of 75.

For the proposed-development condition with 80% impervious, the impervious and pervious areas are 8.0 acres and 2.0 acres, respectively. The impervious area CN-value is 98. The 2.0 acres of pervious area consists of 70 percent grass landscaping covering the same proportions of Garfield and Bonner soil (80% and 20% respectively). Therefore, CNs of 79 and 69 are read from Table 4.5.2 fair condition open space and area weighted to obtain a pervious area CN value of 77. The results of this example are summarized in the following table:

On-Site Condition	Existing	Proposed
Land use	Woods	Multi-Family
Pervious area	10.0 ac.	2.0 ac.
CN of pervious area	75	77
Impervious area	0 ac	8.0 ac
CN of impervious area	---	98

SCS Curve Number Equations: The rainfall-runoff equation of the SCS curve number method relate a land area's runoff depth (precipitation excess) to the precipitation it receives and to its natural storage capacity. The amount of runoff from a given watershed is solved with the following equations:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$

$$S = \frac{1000}{CN} - 10$$

$$Q = 0 \quad \textit{for} \quad P < 0.2S$$

where:

Q = the actual direct runoff depth (inches)

P = the total rainfall depth over the area (inches)

S = the potential abstraction or potential maximum natural detention over the area due to infiltration, storage, etc. (inches)

CN = the runoff curve number

The combination of the above equations allows for estimation of the total runoff volume by computing the total runoff depth, Q, given the total precipitation depth, P for the storm of interest.

Example: The following is an example for determining design treatment volume.

Project location:	Walla Walla
Area requiring treatment:	4.5 acres, paved surfaces
CN:	98
S:	(1000/98) – 10 = 0.20
$P_{2\text{-year},24\text{-hour}}$, from Figure 4.3.3:	1.2 inches
C_{wqs} for Region 3, from Table 4.2.9:	0.69
24-hour to regional storm precipitation depth conversion factor for Region 3, from Table 4.2.10:	1.06

The total amount of rainfall during the **24-hour storm** is:

$$P_{wqs} = C_{wqs} * P_{2\text{-year},24\text{-hour}} = (0.69)\ (1.2 \text{ inches}) = 0.83 \text{ inches}$$

The total amount of rainfall during the **regional storm** is:

P_{wqs} = (0.69) (1.2 inches) (1.06) = 0.88 inches

Continuing on with the rainfall from the **regional storm**, the amount (*depth*) of rainfall that becomes runoff is:

$Q = [0.88 - 0.2\,(0.20)]^2 / [0.88 + 0.8\,(0.20)] = 0.68$ inches

This depth value represents inches over the entire contributing area. The total *volume* of runoff is found by multiplying this depth by the area, with necessary conversion from inches*acres to cubic feet:

Total runoff volume (ft^3) = (3,630 ft^3/acre-in) (Q) (A)

The **total runoff volume** is:

3,630 ft^3/acre-in * 0.68 inches * 4.5 acres = 11,108 ft^3

This is the basis for design of runoff treatment BMPs for which the design is based on the total volume of runoff during the water quality design storm.

When developing the runoff hydrograph, the above equation for Q is used to compute the incremental runoff depth for each time interval from the incremental precipitation depth given by the design storm hyetograph. This time distribution of runoff depth is often referred to as the precipitation excess and provides the basis for synthesizing the runoff hydrograph.

4.6 Level-Pool Routing Method

This section presents a general description of the methodology for routing a hydrograph through an existing retention/detention facility or closed depression, or for sizing a new retention/detention facility using hydrograph analysis.

The "level pool routing" technique presented here is one of the simplest and most commonly used hydrograph routing methods. This method is described in "Handbook of Applied Hydrology," Chow, Ven Te, 1964, and elsewhere, and is based on the continuity equation:

Inflow - Outflow = Change in storage

$$\left[\frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2}\right] = \frac{\Delta S}{\Delta t} = S_2 - S_1$$

where: I = Inflow at time 1 and time 2

O = Outflow at time 1 and time 2

S = Storage at time 1 and time 2

Δt = Time interval, or time 2 minus time 1

The time interval, Δt, must be consistent with the time interval used in developing the inflow hydrograph. The time interval used for the 6-hour storm is 5 minutes while the time interval for the 72-hour storm is 30 minutes. The Δt variable can be eliminated by dividing it into the storage variables to obtain the following rearranged equation:

$$I_1 + I_2 + 2S_1 - O_1 = O_2 + 2S_2$$

If the time interval, Δt, is in minutes, the units of storage (S) are now [cubic feet/min] which can be converted to cfs by multiplying by 1 min/60 sec.

The terms on the left-hand side of the equation are known from the inflow hydrograph and from the storage and outflow values of the previous time step. The unknowns O_2 and S_2 can be solved interactively from the given stage-storage and stage-discharge curves.

The following steps are required in performing level-pool hydrograph routing:

- Develop stage-storage relationship, which is a function of inflow and pond geometry.
- Develop the routing curve for the hydrograph and pond, which is a graph of outflow from the pond at a given stage versus the quantity O + 2S for the same stage. The outflow is a function of stage (head above the orifice) and the control structure configuration.
- Route the inflow hydrograph through the proposed facility by applying the continuity equation above at each time step, where the inflow hydrograph supplies values of I, the stage-storage relationship supplies values of S, and the routing curve supplies values of O.

The commercially available SBUH hydrograph computer models use the level pool routing methodology to shift hydrographs and size infiltration and detention facilities.

4.7 Rational Method

4.7.1 Introduction

The primary source for this section is the WSDOT Hydraulics Manual, 1998.

Applicability: The rational method is an allowable method for computing peak runoff rates for flow based runoff treatment BMPs such as biofiltration swales and oil/water separators. It is also a common method for computing the peak runoff rate for design of drywells and conveyance systems.

Supplemental Guidelines: The greatest accuracy is obtained for areas smaller than 100 acres and for developed conditions with large areas of impervious surface (e.g., pavement, roof tops). Basins up to 1,000 acres may be evaluated using the rational formula; however, results for large basins often do not properly account for effects of infiltration and thus are less accurate.

Procedure: Design peak runoff rates may be determined by the Rational formula:

$$\mathbf{Q = C\,I\,A}$$

where: **Q** = Runoff, in cubic feet per second
C = Runoff coefficient
I = Rainfall intensity, in inches per hour
A = Contributing area, in acres

The runoff coefficient C should be based on Table 4.7.1.

The coefficients in Table 4.7.1 are applicable for peak storms of 10-year or less frequency. Less frequent, higher intensity storms will require the use of higher coefficients because infiltration and other losses have a proportionally smaller effect on runoff. Generally, the coefficient should be increased by 10 percent when designing for a 25-year frequency; by 20 percent for 50-year; and by 25 percent for 100-year. The runoff coefficient should not be increased above 0.90.

The equation for calculating rainfall intensity is:

$$\mathbf{I = m / (T_c)^n}$$

where: **I** = Rainfall intensity, in inches per hour

$\mathbf{T_c}$ = Time of concentration, in minutes; and

m *and* **n** = rainfall intensity coefficients, from Table 4.7.2 for selected cities in eastern Washington; these coefficients have been determined for all major cities for the 2-, 10-, 25-, 50-, and 100-year mean recurrence intervals (MRI) based on NOAA Atlas 2.

4.7.2 Time of Concentration for Rational Method

If rainfall is applied at a constant rate over a drainage basin, it would eventually produce a constant peak rate of runoff. The amount of time that passes from the moment that the constant rainfall begins to the moment that the constant rate of runoff begins is called the time of concentration. This is the time required for the surface runoff to flow from the most hydraulically remote part of the drainage basin to the location of concern.

Actual precipitation does not fall at a constant rate. A precipitation event will generally begin with low rainfall intensity and then, sometimes very quickly, build to peak intensity, and eventually taper down to no rainfall. Because rainfall intensity is variable, the time of concentration is included in the rational method so that the designer can determine the proper rainfall intensity to apply across the basin. The intensity that should be used for design purposes is the highest intensity that will occur with the entire basin contributing flow to the location where the designer is interested in knowing the flow rate. It is important to note that this may be a much lower intensity than the absolute maximum intensity. The reason is that it often takes several minutes before the entire basin is contributing flow but the absolute maximum intensity lasts for a much shorter time so the rainfall intensity that creates the greatest runoff is less than the maximum by the time the entire basin is contributing flow.

Most drainage basins will consist of different types of ground covers and conveyance systems that flow must pass over or through. These are referred to as flow segments. It is common for a basin to have flow segments that are overland flow and flow segments that are open channel flow. Urban drainage basins often have flow segments that are flow through a storm drain pipe in addition to the other two types. A travel time (the amount of time required for flow to move through a flow segment) must be computed for each flow segment. The time of concentration is equal to the sum of all the flow segment travel times.

For a few drainage areas, a unique situation occurs where the time of concentration that produces the largest amount of runoff is less than the time of concentration for the entire basin. This can occur when two or more sub-basins have dramatically different types of cover (i.e., different runoff coefficients). The most common case would be a large paved area together with a long narrow strip of natural area. In this case, the designer should check the runoff produced by the paved area alone to determine if this scenario would cause a greater peak runoff rate than the peak runoff rate produced when both land segments are contributing flow. The scenario that produces the greatest runoff should be used, even if the entire basin is not contributing flow to this runoff.

The procedure described below for determining the time of concentration for overland flow was developed by the United States Natural Resources Conservation Service (formerly known as the Soil Conservation Service). It is sensitive to slope, type of ground cover, and the size of channel. The designer should never use a time of concentration less than 5 minutes. The time of concentration can be calculated as follows:

$$\mathbf{T_c = T_{t1} + T_{t2} + \ldots + T_{tn}}$$

using:

$$\mathbf{T_t = L / (k * (S)^{0.5})} \quad \textit{or} \quad \mathbf{T_t = L^{1.5} / (k * (\Delta H)^{0.5})}$$

where:
- $\mathbf{T_c}$ = Time of concentration, in minutes
- $\mathbf{T_t}$ = Travel time of flow segment, in minutes
- **L** = Length of segment, in feet
- **k** = Ground cover coefficient from Table 4.7.3, in feet/minute
- **S** = Slope of segment, in feet/feet
- $\mathbf{\Delta H}$ = Change in elevation of segment, in feet

Table 4.7.1 Values of runoff coefficient "C" for use in Rational Method with return intervals of 10 years or less.
See text section 4.7.1 for use with greater return intervals.

COVER	FLAT	ROLLING 2% - 10%	HILLY OVER 10%
Pavement and Roofs	0.90	0.90	0.90
Earth Shoulders	0.50	0.50	0.50
Drives and Walks	0.75	0.80	0.85
Gravel Pavement	0.50	0.55	0.60
City Business Areas	0.80	0.85	0.85
Suburban Residential*	0.25	0.35	0.40
Single Family Residential*	0.30	0.40	0.50
Lawns, Sandy Soil	0.10	0.15	0.20
Lawn, Heavy Soil	0.17	0.22	0.35
Grass Shoulders	0.25	0.25	0.25
Side Slopes, Earth	0.60	0.60	0.60
Side Slopes, Turf	0.30	0.30	0.30
Median Areas, Turf	0.25	0.30	0.30
Cultivated Land, Clay and Loam	0.50	0.55	0.60
Cultivated Land, Sand and Gravel	0.25	0.30	0.35
Industrial Areas, Light	0.50	0.70	0.80
Industrial Areas, Heavy	0.60	0.80	0.90
Parks and Cemeteries	0.10	0.15	0.25
Playgrounds	0.20	0.25	0.30
Woodland and Forests	0.10	0.15	0.20
Meadows and Pasture Land	0.25	0.30	0.35
Pasture with Frozen Ground	0.40	0.45	0.50

Source: WSDOT Hydraulics Manual, January 1997

Table 4.7.2 Values of rainfall coefficients m and n for selected cities

Location	2-Year MRI		10-Year MRI		25-Year MRI		50-Year MRI		100-Year MRI	
	m	n	m	n	m	n	m	n	m	n
Clarkston and Colfax	5.02	0.628	8.24	0.635	10.07	0.638	11.45	0.639	12.81	0.639
Colville	3.48	0.558	6.98	0.610	9.07	0.626	10.65	0.635	12.26	0.642
Ellensburg	2.89	0.590	7.00	0.649	9.43	0.664	11.30	0.672	13.18	0.678
Leavenworth	3.04	0.530	5.62	0.575	7.94	0.594	9.75	0.606	11.08	0.611
Moses Lake	2.61	0.583	6.99	0.655	9.58	0.671	11.61	0.681	13.63	0.688
Omak	3.04	0.583	6.63	0.633	8.74	0.647	10.35	0.654	11.97	0.660
Pasco and Kennewick	2.89	0.590	7.00	0.649	9.43	0.664	11.30	0.672	13.18	0.678
Snoqualmie Pass	3.61	0.417	6.56	0.459	7.72	0.459	8.78	0.461	10.21	0.476
Spokane	3.47	0.556	6.98	0.609	9.09	0.626	10.68	0.635	12.33	0.643
Stevens Pass	4.73	0.462	8.19	0.500	8.53	0.484	10.61	0.499	12.45	0.513
Walla Walla	3.33	0.569	7.30	0.627	9.67	0.645	11.45	0.653	13.28	0.660
Wenatchee	3.15	0.535	6.19	0.579	7.94	0.592	9.32	0.600	10.68	0.605
Yakima	3.86	0.608	7.37	0.644	9.40	0.654	10.93	0.659	12.47	0.663

Source: WSDOT Hydraulics Manual, January 1997 *Note: MRI = Mean Recurrence Interval*

Table 4.7.3 Values of ground cover coefficient k

Cover or channel type		k
Forest with heavy ground cover		150
Minimum tillage cultivation		280
Short pasture grass or lawn		420
Nearly bare ground		600
Small roadside ditch w/grass		900
Paved area		1,200
Gutter flow	4 in. deep	1,500
	6 in. deep	2,400
	8 in. deep	3,100
Storm sewer	12 in. diameter	3,000
	18 in. diameter	3,900
	24 in. diameter	4,700
Open channel flow (n = 0.040)	1 ft. deep	1,100
in a narrow channel (w/d = 1)	2 ft. deep	1,800
	4 ft. deep	2,800
Open channel flow (n = 0.040)	1 ft. deep	2,000
in a wide channel (w/d = 9)	2 ft. deep	3,100
	4 ft. deep	5,000

Source: WSDOT Hydraulics Manual, January 1997

Appendix 4A – Background Information on Design Storms and Selected Modeling Methods

As an early step in the process of developing a technical stormwater manual, short- and long-duration design storms were identified for eastern Washington by MGS Engineering Consultants at the request of to the Eastern Washington Stormwater Management Project Steering Committee. Questions were raised by some members of the Manual Subcommittee and during the public review and comment period on the first draft of the manual concerning the practical application and reliability of using the long-duration design storms as input for commonly used modeling methods and software. For the final draft version of the Manual, subsequent work by Harper Houf Righellis, Inc. was done at the request of the Eastern Washington Stormwater Management Project Manual Subcommittee and Technical Advisory Group. Harper Houf Righellis, Inc. reviewed the work done by MGS Engineering Consultants and recommended appropriate modeling approaches for use by the general engineering and project design community.

This appendix contains a summary description of the work done by both MGS Engineering Consultants (Section 4.A.1) and Harper Houf Righellis, Inc. (Section 4.A.2).

Appendices 4B and 4C provide additional detailed information about the short-and long-duration design storms: the precipitation data used to identify the four climatic regions of eastern Washington and generate the storms; and the resulting 72-hour, two-peak hyetographs for each of the four regions.

The 72-hour long-duration hyetographs published Appendix 4C are not currently recommended for direct use. There is concern that the single event hydrograph methods do not produce realistic results when using multiple peak hyetographs. In the SCS method, the initial abstraction (loss) is computed from the first contribution of rainfall with no accounting for the dry period between the two hyetographs to allow for initial abstraction again. This produces greater peak flows and runoff volumes than would otherwise be computed using just the second hyetograph, even while the first hyetograph is not sufficient to generate direct runoff or substantially increase soil moisture present at the start of the second hyetograph.

Updated information on modeling methods and input data will be posted on the Department of Ecology's website as it becomes available.

4A-1 Development of Short- and Long-Duration Design Storms for Eastern Washington

by MGS Engineering Consultants

Overview of Storm Types

There are two storm types of interest for stormwater analyses in eastern Washington. Short-duration thunderstorms can occur in the late spring through early fall seasons and are characterized by high intensities for short periods of time over localized areas. These types of storms can produce high rates of runoff and flash-flooding and are important where flood peak discharge and/or erosion are design considerations.

Long-duration general storms can occur at anytime of the year, but are more common in the late fall through winter period, and in the late spring and early summer periods. General storms in eastern Washington are characterized by sequences of storm activity and intervening dry periods, often occurring over several days. Low to moderate intensity precipitation is typical during the periods of storm activity. These types of events can produce floods with large runoff volumes and moderate peak discharge. The runoff volume can be augmented by snowmelt when precipitation falls on snow during winter and early spring storms. These types of storm events are important where both runoff volume and peak discharge are design considerations.

Design storms are constructed utilizing two components: a precipitation magnitude for a specified duration and a dimensionless storm pattern. The precipitation magnitude for the specified duration is determined based on the desired level of service (return period of the storm, years) and is used to scale the dimensionless storm pattern to produce the design storm. Specifically, the 2-hour precipitation amount for a selected return period is used for scaling the short-duration thunderstorm. The 24-hour precipitation amount for a selected return period is used for scaling the long-duration general storm.

This appendix provides information on the methods and data that were used for analysis and development of design storms for both short-duration thunderstorms and long-duration general storms. The dimensionless storm patterns for the short-duration thunderstorm and long-duration general storm were developed from analyses of historical storms and contain storm characteristics that are representative of the conditions frequently observed in significant storms.

Climatic Regions

Eastern Washington has been divided into four climatic regions to reflect differences in storm characteristics and the seasonality of storms. The four climatic regions (see Figure 4.3.1) include:

Region 1 – East Slopes of Cascade Mountains

This region is comprised of mountain areas on the east slopes of the Cascade Mountains. It is bounded to the west by the Cascade crest and bounded to the east by a generalized contour line of 16-inches mean annual precipitation.

Region 2 – Central Basin

The Central Basin region is comprised of the Columbia Basin and adjacent low elevation areas in central Washington. It is bounded to the west by the generalized contour line of 16-inches mean annual precipitation that forms the east slopes of the Cascade Mountains, and bounded to the north and east by the contour line of 14-inches mean annual precipitation. Many of the larger cities in eastern Washington are in this region including: Ellensburg, Kennewick, Moses Lake, Pasco, Richland, Wenatchee, and Yakima.

Region 3 – Okanogan, Spokane, Palouse

This region is comprised of inter-mountain areas and includes areas near Okanogan, Spokane, and the Palouse. It is bounded to the west by the east slopes of the Cascade Mountains and the Central Basin, bounded to the northeast by the Kettle River Range and Selkirk Mountains, and bounded to the southeast by the Blue Mountains. It generally occupies an area with mean annual precipitation ranging from 14-inches to 22-inches.

Region 4 – Northeastern Mountains and Blue Mountains

This region is comprised of mountain areas in the easternmost part of Washington State. It includes portions of the Kettle River Range and Selkirk Mountains in the northeast, and includes the Blue Mountains in the southeast corner of eastern Washington. Mean annual precipitation ranges from a minimum of 22-inches to over 60-inches. The western boundary of this region is a generalized contour line of 22-inches mean annual precipitation.

Seasonality of Storms

Information on the seasonality of storms is useful in providing information for selection of antecedent conditions to be used with the design storms for rainfall-runoff modeling at undeveloped sites.

Short-duration thunderstorms are warm season events that occur from late spring through early fall throughout eastern Washington (Figure 4A.1). Antecedent conditions for rainfall-runoff modeling of thunderstorms should be selected consistent with the conditions expected at the time of year when thunderstorms have historically occurred.

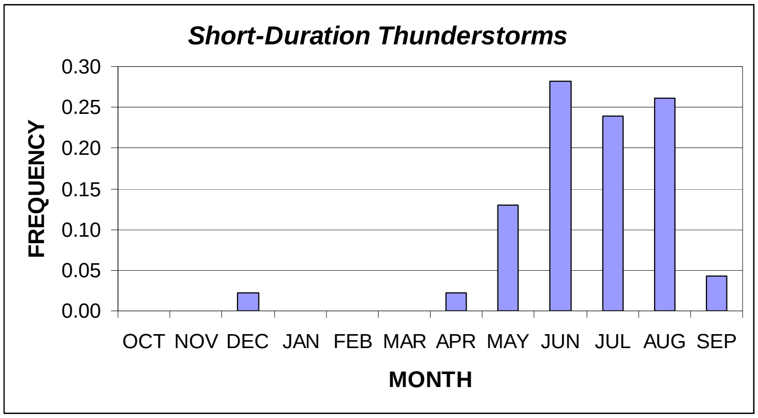


Figure 4A.1 – Seasonality of Short-Duration Thunderstorms in Eastern Washington

The seasonality of long-duration general storms varies across eastern Washington. General storms occur in late fall and winter on the east slopes of the Cascade Mountains (Figure 4A-2a) and are generally associated with concurrent storm activity in western Washington. In contrast, general storms in the more eastern climatic regions may or may not be associated with concurrent storms in western Washington. Long-duration general storms occur in both the cool and warm seasons in the Central Basin, Okanogan, Spokane, and Palouse regions. The storm seasons are reasonably well defined with more frequent storm activity from fall through early spring, and from late spring through early summer (Figure 4A-2b). The seasonality of long-duration general storms in the eastern mountain areas is similar to that for Climatic Regions 2 and 3, except that the winter season is dominant (Figure 4A-2c) with a greater frequency of storm events in the winter season. These seasonalities of storm occurrences should be considered when selecting antecedent conditions for rainfall-runoff modeling.

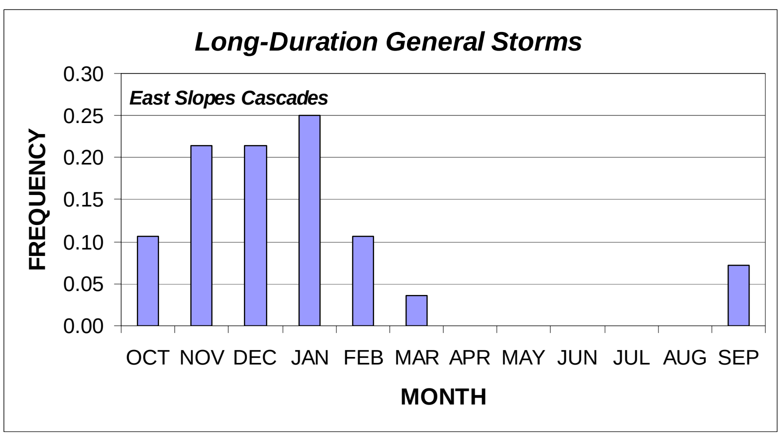


Figure 4A.2a – Seasonality of Long-Duration General Storms for the East Slopes of the Cascade Mountains

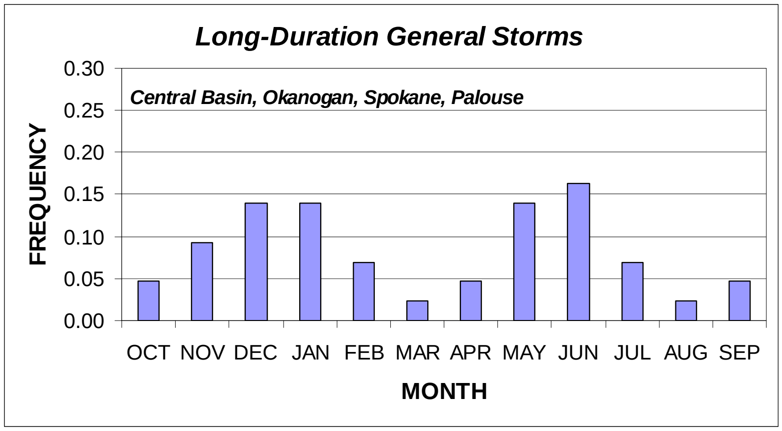


Figure 4A.2b – Seasonality of Long-Duration General Storms for the Central Basin, Okanogan, Spokane, and Palouse

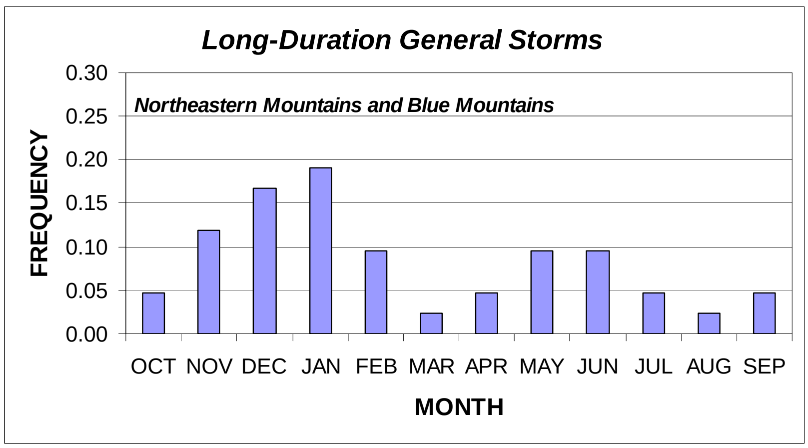


Figure 4A.2c – Seasonality of Long-Duration General Storms for the Northeastern Mountains and Blue Mountains

Dimensionless Design Storm Patterns

The temporal pattern of a design storm is important because it influences the magnitude of the flood peak discharge and runoff volume produced by the storm. Elements of the design storm that are important in rainfall-runoff modeling include: total storm volume; storm duration; maximum intensity during the storm; duration of the high intensity portion(s) of the storm; elapsed time to the high-intensity portion of the storm; and the magnitude, sequencing and temporal pattern of incremental precipitation amounts within the storm. Each of these storm characteristics was examined in the analysis of historical storms in eastern Washington. The storm characteristics were analyzed using a variety of procedures developed by the National Weather Service[3,6], Schaefer[10], and the US Geological Survey[8]. A total of 37 short-duration thunderstorms and 59 long-duration general storms that occurred in the period from 1940 to 2000 were analyzed. Attachment A contains a listing of storm dates, locations, and precipitation amounts for storms that were analyzed.

Dimensionless design storms for the short-duration thunderstorm and long-duration general storm were developed in a manner to contain storm characteristics that are representative of the conditions observed in historical storms. Specifically, mean values of storm characteristics and commonly occurring temporal patterns were used in assembling the design storm temporal patterns.

Long-Duration General Storms

Long-duration general storms in eastern Washington are associated with organized weather systems that produce low to moderate intensity precipitation over broad areas. General storms are typically comprised of sequences of storm activity and intervening dry periods, often occurring over several days. Each of these important characteristics is preserved in the long-duration dimensionless storm patterns.

While many of the characteristics of general storms are similar throughout eastern Washington, some storm characteristics vary by climatic region. For example, in mountain areas, the duration of precipitation is longer and the length of intervening dry periods is shorter, relative to that in the Central Basin. Thus, separate long-duration design storm patterns were needed for each climatic region.

An example of a scaled long-duration design storm is shown in Figure 4A-3, which was obtained by scaling (multiplying) the incremental ordinates of the dimensionless design storm (see Table 4.2.6) by a 24-hour precipitation value of 0.82-inches. Differences in temporal patterns between the four climatic regions can be seen in Figures 4B-1 through 4B-4, which compare long-duration water quality design storms for the four climatic regions.

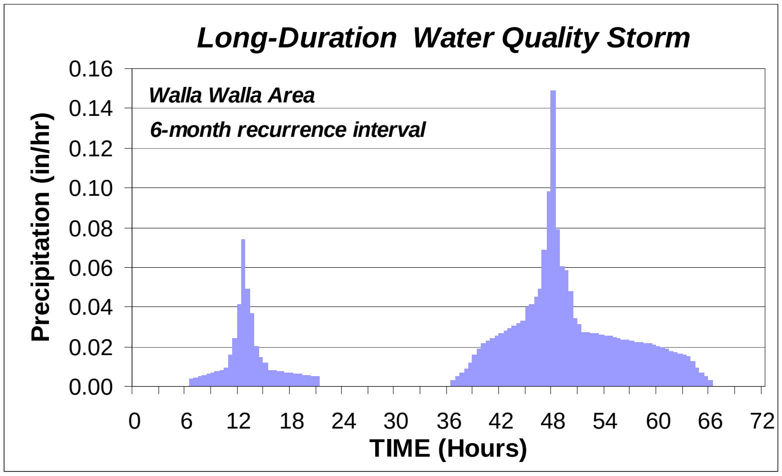


Figure 4A.3 – Example Long-Duration Design Storm

Short-Duration Thunderstorms

Short-duration thunderstorms are characterized by very high-intensity rainfall occurring over isolated areas. The duration of the high-intensity portion of the storm may last from 5 minutes to 30 minutes with a total duration typically ranging from less than an hour to several hours. These storms are convective events, commonly occurring in the late afternoon and early-evening hours in the summer where atmospheric instabilities are often driven by solar heating. They are frequently accompanied by lightning and thunder.

Analysis of historical storms indicates that short-duration thunderstorms have similar characteristics throughout eastern Washington. Therefore, one dimensionless design storm pattern is applicable to all four climatic regions. An example of a scaled short-duration design storm is shown in Figure 4A-4, which was obtained by scaling (multiplying) the incremental ordinates of the dimensionless design storm (see Table 4.2.1) by a 2-hour precipitation value of 0.50-inches.

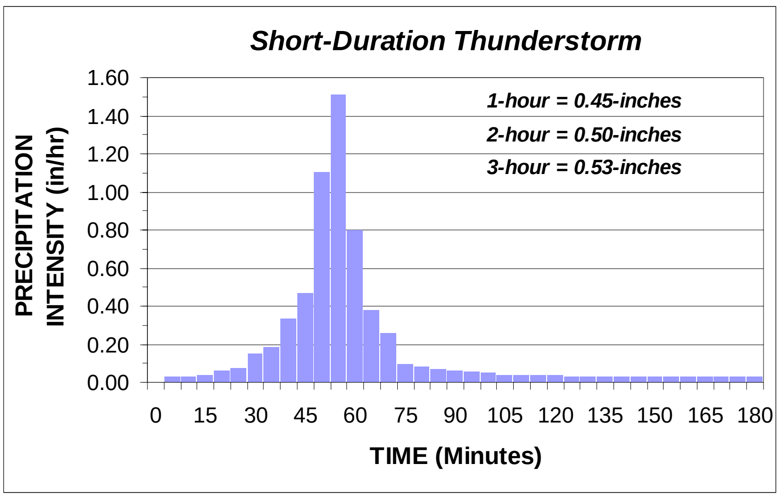


Figure 4A.4 – Example Short-Duration Design Storm

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4A-2 Review of Design Storms and Identification of Best Rainfall-Runoff Modeling Approaches for Eastern Washington

by Harper Houf Righellis, Inc.

Overview

The best available modeling approaches for using short- and long-duration design storms to size runoff treatment and flow control facilities in eastern Washington were identified and recommended in a concurrent effort. A 'big picture' approach was implemented and three storm types were reviewed:

- Short-Duration Storm (3 hour), intended to represent a summer thundershower.
- SCS Type II Storm (24 hour), the standard storm pattern established by the Soil Conservation Service for Eastern Washington. This is not the only storm pattern that can occur. It is the storm pattern that was designated in an era when sizing conveyance facilities (pipes, culverts, channels, and bridges) was a primary consideration and using that storm type produced the maximum peak flow rate.
- Long-Duration Storm (72 hour), intended to represent a winter or spring rainfall.

Review of the Short- and Long-Duration Design Storms

The design storms (short-duration and long-duration) developed by MGS Engineering Consultants appear appropriate in temporal pattern. The short-duration and SCS Type II storms hyetographs are common patterns utilized in arid regions. They are patterns characterized by intense rainfall over relatively short periods within their duration.

The rainfall distributions of the four regional long-duration storm hyetographs do not appear like the majority of the 57 gaged precipitation events used to create the four hyetographs. The gauged multiple peaks appear random. They vary in relative size from small to large, large to small, and sometimes similar. The spacing between peaks varies significantly. From a macro pattern perspective, the long-duration storm hyetographs appear appropriate, but implementation is a concern. Event-based runoff modeling is time dependent, thus hyetograph shape is an important parameter.

The design storms developed by MGS Engineering Consultants appear appropriate in intensities. The precipitation maps and adjustment equations are reasonable.

Identification of Best Rainfall-Runoff Modeling Approaches for Eastern Washington

There are a variety of computational methods available for computing runoff volumes and peak flow rates. Literature other than the work prepared by and cited by MGS Engineering Consultants appears non-existent for arid region long-duration storms. As MGS Engineering Consultants concluded: “Accuracy of uncalibrated runoff estimation methods is generally poor for undeveloped sites in arid and semi-arid environments. Without runoff data for verification, it is not possible to say which of the off-the-shelf runoff estimation methods would likely yield the more accurate results.”

Potential methods are Exponential Loss, Green-Ampt, Holtan, Initial Abstraction and Uniform Loss Rate, Soil Moisture Accounting, Hydrological Simulation Program--Fortran (HSPF), Natural Resources Conservation Service (NRCS) Runoff Curve Number Method, Rational Method, and Regression Equations. Many of these methods could be appropriate for long-duration runoff modeling if calibrated. MGS Engineering Consultants recommended: “The selection of runoff estimation methods should be made from commonly used methods that are readily available in computer programs for computation of runoff hydrographs.”

The above list of commonly used methods is broader than what may be commonly used by design engineers who are not hydrologic specialists. The methods most commonly used by regulatory agencies, design professionals, and software vendors are the SCS Method (NRCS Runoff Curve Number Method), Rational Method, and Regression Equations. Only commonly used methods should be considered until quality data can be collected and rainfall-runoff calibration efforts performed.

With commonly used methods, the expertise of regulatory agencies, design professionals, and software vendors offer the best opportunity to use reasonable input values and produce reasonable output. Thus even though not technically calibrated, results that meet the standard of care for the industry are more likely using common uncalibrated methods than uncommon uncalibrated methods.

Of the three commonly used methods listed above (SCS Method, Rational Method, and Regression Equations), only the SCS Curve Number Method is recommended for computing flow rates and runoff volumes for long-duration storms. The Rational Method is a good method for computing peak flow rates of small urban basins but has no capability to determine reasonable hydrographs and runoff volumes. Regression Equations require quality-measured data to create meaningful regression equations, but necessary data are lacking; peak flow rate determination is the common use of regression equations as runoff volume regression equations appear non-existent.

The SCS Method is commonly used for small and large basins, though method origins are from large rural basins. The engineering community has experience implementing this method.

Discussion and Recommendation of Modified SCS Modeling Approach

Short-Duration Storm (3 hour) and SCS Type II Storm (24 hour)
The short-duration 3-hour storm and the SCS Type II 24-hour storm hyetographs can be directly modeled by readily available hydrologic modeling software and produce intended results.

Long-Duration Storm (72 hour)
The multiple-peak long-duration storm can also be directly modeled by readily available hydrologic modeling software, but does not necessarily produce intended results. NRCS staff has verbally stated that the SCS Method should not be applied to multiple-peak hyetographs. The caution may have been due merely to an unintended use or due to possible computational inaccuracies, but the latter appears to be the case.

With this limitation, another approach is necessary to model the long-duration storm hyetographs. Two key characteristics are apparent from the multiple-peak long-duration hyetographs.

- The first portion of the four regional hyetographs is small compared to the second portion. The first portion of the hyetograph is 16% to 25% of the total hyetograph, depending on the region. For most eastern Washington 72-hour precipitation amounts, the precipitation amount in the first portion hyetograph is diminutive.
- The period of no precipitation between the end of the first portion and beginning of the second portion of the hyetograph ranges from about 12 to 18 hours, depending on the region.

These two characteristics result in hydrographs that have no flow for the entire time between the two hyetographs and sometimes no flow during the first hyetograph. This means there is no compelling reason to directly model the first portion.

If only the second portion needs to be modeled, it may be possible to substitute another standard storm distribution: the SCS Type IA storm pattern of the coastal region of the state where winter rainfall originates. Figure 4A.5 shows only the second portion of the hyetographs for the four regional long-duration storms as cumulative precipitation and the SCS Type IA and Type II 24-hour storms in order to make a visual comparison.

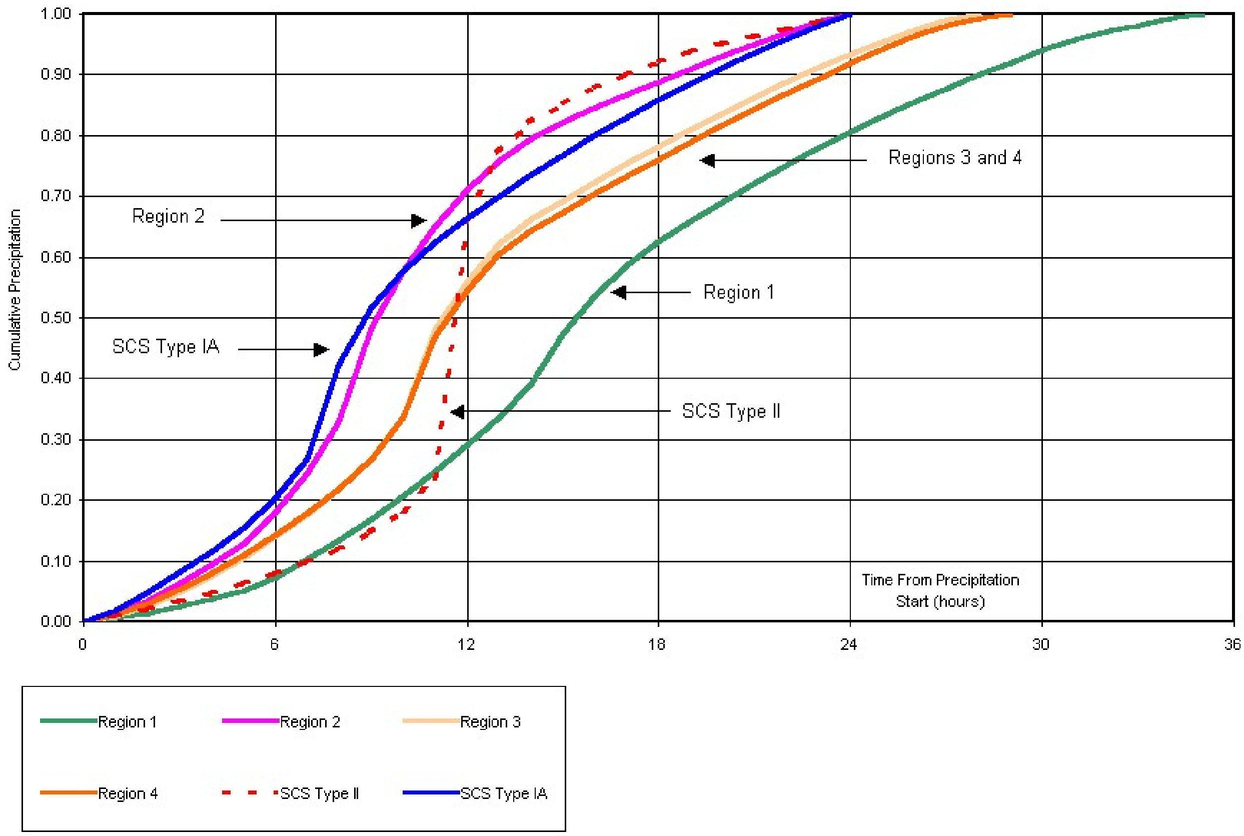

Figure 4A.5 – Standard and Regional Storm Distribution Curves on a Unit Basis

The Type IA storm is similar in shape to the second portion of all four regional long-duration storms. With this similarity, the Type IA may produce acceptable results without the added complexity. Its 24-hour duration allows for easy use of the built-in storm pattern feature of most SCS Method software. This reduces potential for computational errors due to incorrect implementation of unique duration hyetographs.

Actual duration analysis provides computations that more directly reflect the second portion of the long-duration storm hyetographs, but those durations are not precise, they are statistical representations. The following table shows the key comparisons to the Type 1A storm.

Second Portion of Long-Duration Hyetograph	Region 1	Region 2	Region 3	Region 4
Duration (hours)	35	24	28	29
Duration as Ratio of 24 Hours	1.46	1.00	1.16	1.21
Precipitation as Ratio of 24-Hour Precipitation	1.16	1.00	1.06	1.07

Region 1 could be considered for 35-hour duration and 1.16 x 24-hour precipitation storm analysis. 16% more precipitation spread over 46% more time should produce less peak flow but more runoff volume than the Type IA storm. Many of the differences compared to the Type IA storm is in the waning hours of the hyetograph, thus would have less impact than might be expected. The second portions of the long-duration hyetographs for Regions 2, 3, and 4 show no or only minor variation from SCS Type IA 24-hour storm, thus use of 24-hour storm is sufficiently accurate.

<u>Short-Duration Storm (3 hour) and SCS Type II Storm (24 hour)</u>
Modeling of the short-duration three-hour storm and the SCS Type II 24-hour storm are to be per standard methods for those hyetographs.

<u>Long-Duration Storm (72 hour)</u>
The recommended approach for modeling the long-duration storm is as follows.

- Rainfall Modeling:
  Emulate only the second portion of the long-duration storm hyetograph, but account for the first portion by adjusting antecedent moisture conditions.
- Rainfall Distribution:
  Use the SCS Type IA 24-hour storm. This provides the simplest modeling approach and reduces the chance for error by implementing a non-standard hyetograph. If an agency or local jurisdiction prefers the long-duration distributions, the second portion of the long-duration storm hyetograph can be implemented instead.
- Rainfall Intensity:
  Use 24-hour intensity if using the SCS Type IA storm. If using the second portion of the long-duration storm hyetograph, use the precipitation ratio in the table above.
- Curve Numbers:
  Adjust Curve Numbers to account for saturation conditions due to first portion of hyetograph that is not directly modeled. Engineering analysis and judgment is needed for Curve Number adjustment depending on soil characteristics, surface conditions, and first-portion precipitation amount.

Sensitivity Analysis

The primary concern regarding the SCS Method that arose in this study effort was the implementation of the multi-peak hyetographs. To test the concern, HEC-HMS (Hydrologic Engineering Center – Hydrologic Modeling System) was used to compute hydrographs. Three 25-year event hyetographs were modeled for an eight-acre basin with four basin coverage conditions.

For the 72-hour storm, as the initial loss rate decreased, runoff was generated earlier in the second hyetograph than in the SCS Type IA and second-portion only storm hyetographs. This means there was less initial abstraction (loss) computed in the more critical portion of the 72-hour hyetograph than the other storms. This is counterintuitive as the bulk of the 0.55 inches first-portion hyetograph rainfall occurs 24 hours prior to the start of the second hyetograph, thus there should be opportunity for the entire initial loss to occur again at the start of the second hyetograph.

This initial loss computational difference and the impact it may have on second-portion hydrograph flow rates supports the NRCS contention regarding the modeling of multiple peak hyetographs. The peak flow rates computed in the multi-peak long-duration 72-hour storm did not match well with the peak flow rates computed from the other two hyetographs.

Further Recommendations

A future effort of rainfall-runoff data collection and modeling correlation should be undertaken. This will improve the best available science beyond what exists today. Precipitation gages that can measure in small time increments should be placed within drainage basins where runoff flows can be measured in similar small time increments. To be effective, this data collection effort should include broad ranges of drainage basins based on total annual precipitation, elevation, grades, soils types, development types, and degree of development.

Upon storm type segregation, further data analysis should include determination of effective modeling parameters such as lag times and SCS Curve Numbers and comparing them to values commonly used.

Appendix 4B – Historical Storms Used to Develop Design Storms in Eastern Washington

Long-Duration General Storms

Region 1 – Cascade Mountains

PRECIPITATION STATION	STORM DATE	PRECIPITATION 24-HOUR (in)	PRECIPITATION 72-HOUR (in)
Diablo Dam	24-Oct-1945	6.42	9.23
Underwood	11-Dec-1946	4.04	7.27
Hood River Exp Station	6-Jan-1948	3.33	4.53
Diablo Dam	16-Feb-1949	8.12	9.64
Diablo Dam	9-Feb-1951	6.47	12.99
Satus Pass	24-Nov-1960	3.12	4.46
Lucerne 2NNW	19-Nov-1962	3.05	3.45
Mazama	27-Feb-1972	3.80	5.97
Mount Adams RS	13-Jan-1973	6.00	11.39
Satus Pass	15-Jan-1974	3.60	6.05
Lucerne 2NNW	1-Dec-1975	3.17	5.99
Satus Pass	13-Dec-1977	3.30	5.02
Mazama	12-Jan-1980	3.20	3.62
Stehekin 4NW	23-Jan-1982	5.00	6.80
Stevens Pass	3-Dec-1982	6.50	7.40
Carson Fish Hatch	9-Dec-1987	6.20	7.90
Lake Wenatchee	9-Jan-1990	5.30	7.60
Easton	22-Nov-1990	6.40	10.20
Glenwood	27-Oct-1994	3.80	4.10
Easton	8-Feb-1996	4.10	8.90
Glenwood	28-Dec-1998	3.70	4.70

Region 2 – Central Basin

PRECIPITATION STATION	STORM DATE	PRECIPITATION 24-HOUR (in)	PRECIPITATION 72-HOUR (in)
Lind 3NE	25-Jun-1942	1.53	1.77
Harrington 4ENE	21-Sep-1945	1.52	2.10
Coulee Dam 1SW	28-May-1948	1.66	1.74
Harrington 4ENE	25-Sep-1948	1.51	1.65
Centerville	19-Jan-1953	2.36	2.76
Naches 10NW	14-Jan-1956	1.43	1.60
McNary Dam	2-Oct-1957	3.15	3.17
Yakima	24-Dec-1964	1.40	2.83
Harrington 1NW	23-Dec-1966	1.12	1.28
Ellensburg	4-Dec-1974	1.30	2.00
Chief Joe Dam	18-Sep-1986	1.50	1.70
Wenatchee	10-Dec-1987	1.77	1.82
Yakima	19-Nov-1996	1.40	1.57

Region 3 – Okanogan/Spokane/Palouse

PRECIPITATION STATION	STORM DATE	PRECIPITATION 24-HOUR (in)	PRECIPITATION 72-HOUR (in)
Pullman 2NW	15-Sep-1947	2.10	2.60
Oroville	16-Nov-1950	1.96	2.04
Spokane WSO AP	18-Dec-1951	1.58	1.67
Spokane WSO AP	25-Nov-1960	1.41	1.86
Pullman 2NW	22-Nov-1961	1.96	2.52
Dixie 4SE	23-Nov-1964	2.70	2.92
Dayton 9SE	22-Dec-1964	3.01	4.70
Dayton 9SE	2-Jan-1966	2.53	3.69
Moscow 5NE ID	23-Dec-1972	1.80	2.70
Moscow 5NE ID	11-Nov-1973	1.70	2.90
Colville Airport	16-Nov-1973	1.55	1.98
Walla Walla WSO	14-Oct-1980	3.08	3.63
Moscow 5NE ID	9-Feb-1996	1.50	3.20
Whitman Mission	19-Nov-1996	2.00	2.40
Ola ID	27-Dec-1996	3.10	5.00
Republic	27-May-1998	2.50	2.80
Spokane WSO AP	13-Apr-2000	1.53	1.73

Region 4 – Northeastern Mountains and Blue Mountains

PRECIPITATION STATION	STORM DATE	PRECIPITATION 24-HOUR (in)	PRECIPITATION 72-HOUR (in)
Bonners Ferry 1SW	18-Nov-1946	2.78	4.09
Pullman 2NW	15-Sep-1947	2.10	2.60
Pullman 2NW	22-Nov-1961	1.96	2.52
Dayton 9SE	22-Dec-1964	3.01	4.70
Dayton 9SE	2-Jan-1966	2.53	3.69
Moscow 5NE ID	23-Dec-1972	1.80	2.70
Moscow 5NE ID	11-Nov-1973	1.70	2.90
Colville Airport	16-Nov-1973	1.55	1.98
Coeur D Alene RS	15-Jan-1974	1.90	3.70
Dworshak Fish Hatch ID	2-Dec-1977	2.30	2.40
Plummer 3WSW ID	25-Dec-1980	2.10	2.80
Boundary Switchyard	15-Feb-1986	3.10	3.19
Boundary Switchyard	4-Jan-1989	2.30	2.50
Moscow 5NE ID	9-Feb-1996	1.50	3.20
Ola ID	27-Dec-1996	3.10	5.00
Northport	27-May-1998	2.40	2.80

Short-Duration Thunderstorms

All Regions

PRECIPITATION STATION	CLIMATIC REGION	STORM DATE	PRECIPITATION 1-HOUR (in)	PRECIPITATION 2-HOUR (in)
Ellensburg	2	12-May-1943	0.31	0.62
Dayton 1WSW	3	8-Jul-1946	0.78	0.79
Sunnyside	2	7-Jun-1947	1.62	1.62
Oroville	3	16-Jun-1947	1.19	1.25
Methow	2	17-Jun-1950	0.89	0.89
Wilson Creek	2	18-Jun-1950	1.50	1.50
Colville	4	19-Jul-1950	0.92	1.00
Wilson Creek	2	24-Jul-1950	0.80	0.80
Wenatchee Exp Station	2	10-Aug-1952	1.29	1.29
Colville	4	6-Jul-1956	0.81	0.82
Naches 10NW	2	5-May-1957	0.70	0.90
Republic RS	3	5-Jul-1958	1.10	1.10
Methow	2	8-Jul-1958	1.33	1.33
Republic RS	3	9-Aug-1962	1.17	1.26
Pomeroy	3	13-Sep-1966	1.12	1.12
Withrow 4WNW	2	14-Aug-1968	0.64	0.94
Walla Walla WSO	3	26-May-1971	1.64	1.75
Yakima	2	18-Aug-1975	0.70	0.98
Whitman Mission	3	5-Aug-1977	0.94	0.94
Dayton 1WSW	3	7-Jul-1978	1.20	1.20
Boundary Switchyard	4	21-May-1981	0.90	1.10
Naches 10NW	2	7-Jul-1982	1.20	1.20
Chewelah	3	20-Jul-1983	0.90	1.00
Republic RS	3	10-Aug-1983	0.90	1.50
Easton	1	26-Aug-1983	1.80	1.80
Naches 10NW	2	1-Aug-1984	0.80	0.80
Lake Wenatchee	1	11-Feb-1985	0.90	1.10
Mazama	1	16-Jul-1985	1.00	1.10
Diablo Dam	1	20-Jul-1992	0.80	1.10
Chief Joe Dam	2	23-Jul-1992	0.70	1.00
Dixie 4SE	4	7-Aug-1992	0.70	0.90
Boundary Switchyard	4	23-May-1989	1.00	1.00
Chief Joe Dam	2	9-Jul-1993	1.10	1.10
Lind 3NE	2	22-Jul-1993	1.30	1.40
Stevens Pass	1	2-Jun-1998	1.00	1.00
Northport	4	11-Jul-1998	1.10	1.10
Colville	4	3-Jun-1999	1.00	1.90

Appendix 4C – Long-Duration Storm Hyetographs for Eastern Washington

Following are graphical and tabular representations of the long-duration design storms developed by MGS Engineering Consultants.

Note that the 72-hour hyetographs are not unit hyetographs, but have maximum values equal to the ratio of the total 72-hour precipitation to the 24-hour precipitation.

See Appendix 4A for additional information and limitations in applying these hyetographs.

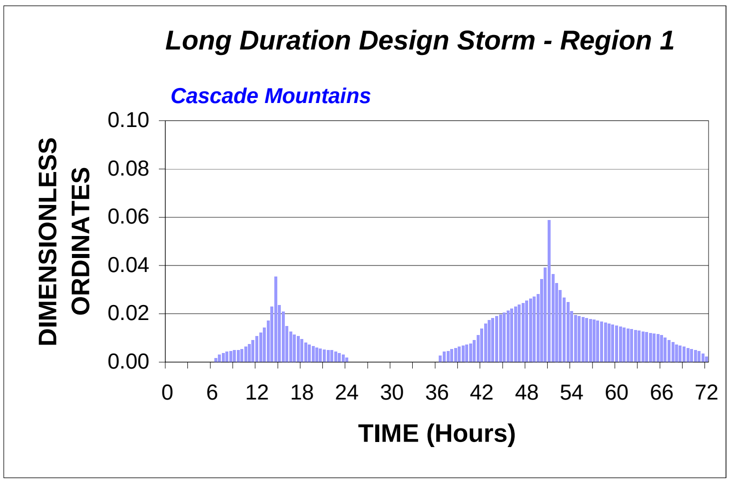

Figure 4B-1

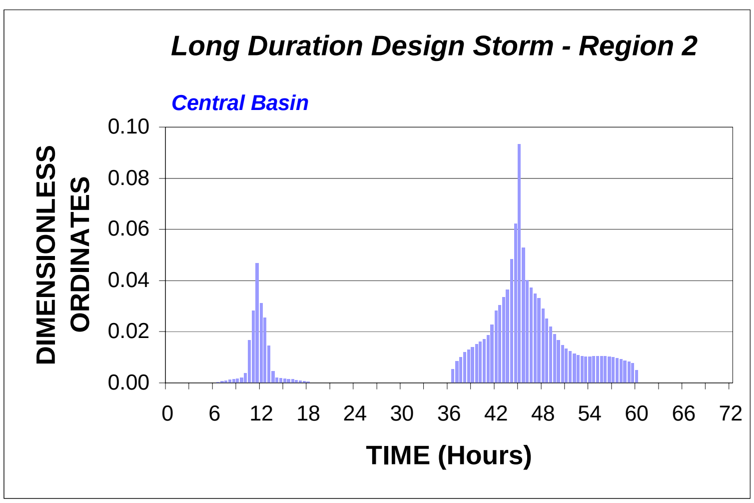

Figure 4B-2

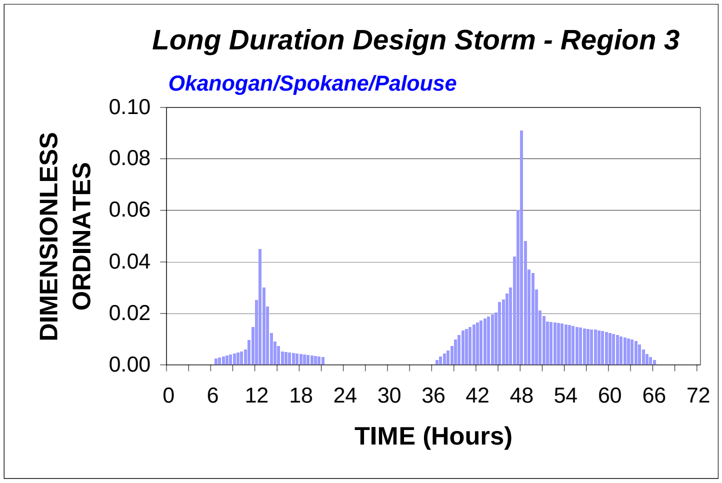

Figure 4B-3

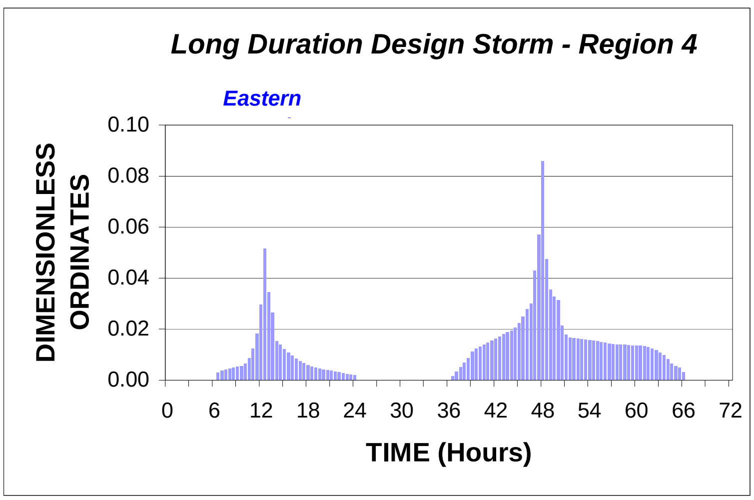

Figure 4B-4

72-Hour Long-Duration Storm Hyetograph Values for Region 1: Cascade Mountains

Note: Use 24-hour precipitation value to scale this storm hyetograph.

Time (hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00179	0.00179
7.0	0.00321	0.00500
7.5	0.00370	0.00870
8.0	0.00420	0.01290
8.5	0.00470	0.01760
9.0	0.00490	0.02250
9.5	0.00510	0.02760
10.0	0.00530	0.03290
10.5	0.00634	0.03924
11.0	0.00740	0.04664
11.5	0.00920	0.05584
12.0	0.01080	0.06664
12.5	0.01214	0.07878
13.0	0.01424	0.09302
13.5	0.01712	0.11014
14.0	0.02288	0.13302
14.5	0.03540	0.16842
15.0	0.02360	0.19202
15.5	0.02101	0.21303
16.0	0.01499	0.22802
16.5	0.01279	0.24081
17.0	0.01144	0.25225
17.5	0.01070	0.26295
18.0	0.00960	0.27255
18.5	0.00814	0.28069
19.0	0.00730	0.28799
19.5	0.00657	0.29456
20.0	0.00598	0.30054
20.5	0.00551	0.30605
21.0	0.00516	0.31121
21.5	0.00494	0.31615
22.0	0.00485	0.32100
22.5	0.00420	0.32520
23.0	0.00370	0.32890
23.5	0.00320	0.33210
24.0	0.00180	0.33390

Time (hours)	Incremental Rainfall	Cumulative Rainfall
24.5	0.00000	0.33390
25.0	0.00000	0.33390
25.5	0.00000	0.33390
26.0	0.00000	0.33390
26.5	0.00000	0.33390
27.0	0.00000	0.33390
27.5	0.00000	0.33390
28.0	0.00000	0.33390
28.5	0.00000	0.33390
29.0	0.00000	0.33390
29.5	0.00000	0.33390
30.0	0.00000	0.33390
30.5	0.00000	0.33390
31.0	0.00000	0.33390
31.5	0.00000	0.33390
32.0	0.00000	0.33390
32.5	0.00000	0.33390
33.0	0.00000	0.33390
33.5	0.00000	0.33390
34.0	0.00000	0.33390
34.5	0.00000	0.33390
35.0	0.00000	0.33390
35.5	0.00000	0.33390
36.0	0.00000	0.33390
36.5	0.00277	0.33667
37.0	0.00423	0.34090
37.5	0.00467	0.34557
38.0	0.00550	0.35107
38.5	0.00590	0.35697
39.0	0.00630	0.36327
39.5	0.00670	0.36997
40.0	0.00723	0.37720
40.5	0.00760	0.38480
41.0	0.00907	0.39387
41.5	0.01116	0.40503
42.0	0.01387	0.41890
42.5	0.01600	0.43490
43.0	0.01740	0.45230
43.5	0.01820	0.47050
44.0	0.01900	0.48950
44.5	0.01980	0.50930
45.0	0.02060	0.52990
45.5	0.02140	0.55130
46.0	0.02220	0.57350
46.5	0.02300	0.59650
47.0	0.02380	0.62030
47.5	0.02460	0.64490
48.0	0.02550	0.67040
48.5	0.02620	0.69660

Time (hours)	Incremental Rainfall	Cumulative Rainfall
49.0	0.02720	0.72380
49.5	0.02820	0.75200
50.0	0.03445	0.78645
50.5	0.03920	0.82565
51.0	0.05880	0.88445
51.5	0.03652	0.92097
52.0	0.03280	0.95377
52.5	0.02980	0.98357
53.0	0.02680	1.01037
53.5	0.02484	1.03521
54.0	0.02116	1.05637
54.5	0.01943	1.07580
55.0	0.01910	1.09490
55.5	0.01870	1.11360
56.0	0.01830	1.13190
56.5	0.01790	1.14980
57.0	0.01750	1.16730
57.5	0.01710	1.18440
58.0	0.01670	1.20110
58.5	0.01630	1.21740
59.0	0.01590	1.23330
59.5	0.01550	1.24880
60.0	0.01510	1.26390
60.5	0.01470	1.27860
61.0	0.01430	1.29290
61.5	0.01390	1.30680
62.0	0.01360	1.32040
62.5	0.01330	1.33370
63.0	0.01300	1.34670
63.5	0.01270	1.35940
64.0	0.01240	1.37180
64.5	0.01210	1.38390
65.0	0.01180	1.39570
65.5	0.01150	1.40720
66.0	0.01120	1.41840
66.5	0.01020	1.42860
67.0	0.00920	1.43780
67.5	0.00820	1.44600
68.0	0.00734	1.45334
68.5	0.00675	1.46009
69.0	0.00630	1.46639
69.5	0.00585	1.47224
70.0	0.00540	1.47764
70.5	0.00495	1.48259
71.0	0.00450	1.48709
71.5	0.00350	1.49059
72.0	0.00225	1.49284

72-Hour Long-Duration Storm Hyetograph Values for Region 2: Central Basin

Note: Use 24-hour precipitation value to scale this storm hyetograph.

Time (hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00030	0.00030
7.0	0.00060	0.00090
7.5	0.00090	0.00180
8.0	0.00120	0.00300
8.5	0.00150	0.00450
9.0	0.00180	0.00630
9.5	0.00210	0.00840
10.0	0.00394	0.01234
10.5	0.01669	0.02903
11.0	0.02831	0.05734
11.5	0.04680	0.10414
12.0	0.03120	0.13534
12.5	0.02549	0.16083
13.0	0.01451	0.17534
13.5	0.00445	0.17979
14.0	0.00202	0.18181
14.5	0.00192	0.18373
15.0	0.00172	0.18545
15.5	0.00152	0.18697
16.0	0.00132	0.18829
16.5	0.00112	0.18941
17.0	0.00092	0.19033
17.5	0.00072	0.19105
18.0	0.00052	0.19157
18.5	0.00000	0.19157
19.0	0.00000	0.19157
19.5	0.00000	0.19157
20.0	0.00000	0.19157
20.5	0.00000	0.19157
21.0	0.00000	0.19157
21.5	0.00000	0.19157
22.0	0.00000	0.19157
22.5	0.00000	0.19157
23.0	0.00000	0.19157
23.5	0.00000	0.19157
24.0	0.00000	0.19157

Time (hours)	Incremental Rainfall	Cumulative Rainfall
24.5	0.00000	0.19157
25.0	0.00000	0.19157
25.5	0.00000	0.19157
26.0	0.00000	0.19157
26.5	0.00000	0.19157
27.0	0.00000	0.19157
27.5	0.00000	0.19157
28.0	0.00000	0.19157
28.5	0.00000	0.19157
29.0	0.00000	0.19157
29.5	0.00000	0.19157
30.0	0.00000	0.19157
30.5	0.00000	0.19157
31.0	0.00000	0.19157
31.5	0.00000	0.19157
32.0	0.00000	0.19157
32.5	0.00000	0.19157
33.0	0.00000	0.19157
33.5	0.00000	0.19157
34.0	0.00000	0.19157
34.5	0.00000	0.19157
35.0	0.00000	0.19157
35.5	0.00000	0.19157
36.0	0.00000	0.19157
36.5	0.00544	0.19701
37.0	0.00856	0.20557
37.5	0.01000	0.21557
38.0	0.01200	0.22757
38.5	0.01300	0.24057
39.0	0.01400	0.25457
39.5	0.01500	0.26957
40.0	0.01600	0.28557
40.5	0.01700	0.30257
41.0	0.01869	0.32126
41.5	0.02281	0.34407
42.0	0.02832	0.37239
42.5	0.03050	0.40289
43.0	0.03350	0.43639
43.5	0.03650	0.47289
44.0	0.04842	0.52131
44.5	0.06220	0.58351
45.0	0.09330	0.67681
45.5	0.05275	0.72956
46.0	0.04025	0.76981
46.5	0.03717	0.80698
47.0	0.03483	0.84181
47.5	0.03307	0.87488
48.0	0.02893	0.90381
48.5	0.02519	0.92900

Time (hours)	Incremental Rainfall	Cumulative Rainfall
49.0	0.02189	0.95089
49.5	0.01906	0.96995
50.0	0.01670	0.98665
50.5	0.01480	1.00145
51.0	0.01336	1.01481
51.5	0.01234	1.02715
52.0	0.01156	1.03871
52.5	0.01096	1.04967
53.0	0.01054	1.06021
53.5	0.01032	1.07053
54.0	0.01028	1.08081
54.5	0.01038	1.09119
55.0	0.01046	1.10165
55.5	0.01046	1.11211
56.0	0.01040	1.12251
56.5	0.01025	1.13276
57.0	0.01004	1.14280
57.5	0.00974	1.15254
58.0	0.00926	1.16180
58.5	0.00868	1.17048
59.0	0.00832	1.17880
59.5	0.00781	1.18661
60.0	0.00500	1.19161
60.5	0.00000	1.19161
61.0	0.00000	1.19161
61.5	0.00000	1.19161
62.0	0.00000	1.19161
62.5	0.00000	1.19161
63.0	0.00000	1.19161
63.5	0.00000	1.19161
64.0	0.00000	1.19161
64.5	0.00000	1.19161
65.0	0.00000	1.19161
65.5	0.00000	1.19161
66.0	0.00000	1.19161
66.5	0.00000	1.19161
67.0	0.00000	1.19161
67.5	0.00000	1.19161
68.0	0.00000	1.19161
68.5	0.00000	1.19161
69.0	0.00000	1.19161
69.5	0.00000	1.19161
70.0	0.00000	1.19161
70.5	0.00000	1.19161
71.0	0.00000	1.19161
71.5	0.00000	1.19161
72.0	0.00000	1.19161

72-Hour Long-Duration Storm Hyetograph Values for Region 3: Okanogan, Spokane, Palouse

Note: Use 24-hour precipitation value to scale this storm hyetograph.

Time (hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00240	0.00240
7.0	0.00280	0.00520
7.5	0.00320	0.00840
8.0	0.00360	0.01200
8.5	0.00403	0.01603
9.0	0.00440	0.02043
9.5	0.00480	0.02523
10.0	0.00520	0.03043
10.5	0.00600	0.03643
11.0	0.00968	0.04611
11.5	0.01476	0.06087
12.0	0.02524	0.08611
12.5	0.04500	0.13111
13.0	0.03000	0.16111
13.5	0.02267	0.18378
14.0	0.01233	0.19611
14.5	0.00901	0.20512
15.0	0.00731	0.21243
15.5	0.00520	0.21763
16.0	0.00500	0.22263
16.5	0.00480	0.22743
17.0	0.00460	0.23203
17.5	0.00440	0.23643
18.0	0.00420	0.24063
18.5	0.00400	0.24463
19.0	0.00380	0.24843
19.5	0.00360	0.25203
20.0	0.00340	0.25543
20.5	0.00320	0.25863
21.0	0.00300	0.26163
21.5	0.00000	0.26163
22.0	0.00000	0.26163
22.5	0.00000	0.26163
23.0	0.00000	0.26163
23.5	0.00000	0.26163
24.0	0.00000	0.26163

Time (hours)	Incremental Rainfall	Cumulative Rainfall
24.5	0.00000	0.26163
25.0	0.00000	0.26163
25.5	0.00000	0.26163
26.0	0.00000	0.26163
26.5	0.00000	0.26163
27.0	0.00000	0.26163
27.5	0.00000	0.26163
28.0	0.00000	0.26163
28.5	0.00000	0.26163
29.0	0.00000	0.26163
29.5	0.00000	0.26163
30.0	0.00000	0.26163
30.5	0.00000	0.26163
31.0	0.00000	0.26163
31.5	0.00000	0.26163
32.0	0.00000	0.26163
32.5	0.00000	0.26163
33.0	0.00000	0.26163
33.5	0.00000	0.26163
34.0	0.00000	0.26163
34.5	0.00000	0.26163
35.0	0.00000	0.26163
35.5	0.00000	0.26163
36.0	0.00000	0.26163
36.5	0.00180	0.26343
37.0	0.00320	0.26663
37.5	0.00437	0.27100
38.0	0.00563	0.27663
38.5	0.00722	0.28385
39.0	0.00978	0.29363
39.5	0.01150	0.30513
40.0	0.01340	0.31853
40.5	0.01400	0.33253
41.0	0.01480	0.34733
41.5	0.01560	0.36293
42.0	0.01640	0.37933
42.5	0.01720	0.39653
43.0	0.01800	0.41453
43.5	0.01880	0.43333
44.0	0.01960	0.45293
44.5	0.02040	0.47333
45.0	0.02430	0.49763
45.5	0.02534	0.52297
46.0	0.02766	0.55063
46.5	0.03000	0.58063
47.0	0.04200	0.62263
47.5	0.06000	0.68263
48.0	0.09100	0.77363
48.5	0.04801	0.82164

Time (hours)	Incremental Rainfall	Cumulative Rainfall
49.0	0.03700	0.85864
49.5	0.03568	0.89432
50.0	0.02932	0.92364
50.5	0.02114	0.94478
51.0	0.01900	0.96378
51.5	0.01680	0.98058
52.0	0.01660	0.99718
52.5	0.01640	1.01358
53.0	0.01620	1.02978
53.5	0.01600	1.04578
54.0	0.01570	1.06148
54.5	0.01540	1.07688
55.0	0.01510	1.09198
55.5	0.01480	1.10678
56.0	0.01450	1.12128
56.5	0.01420	1.13548
57.0	0.01390	1.14938
57.5	0.01379	1.16317
58.0	0.01361	1.17678
58.5	0.01338	1.19016
59.0	0.01310	1.20326
59.5	0.01276	1.21602
60.0	0.01236	1.22838
60.5	0.01192	1.24030
61.0	0.01148	1.25178
61.5	0.01104	1.26282
62.0	0.01061	1.27343
62.5	0.01018	1.28361
63.0	0.00976	1.29337
63.5	0.00918	1.30255
64.0	0.00782	1.31037
64.5	0.00579	1.31616
65.0	0.00421	1.32037
65.5	0.00315	1.32352
66.0	0.00185	1.32537
66.5	0.00000	1.32537
67.0	0.00000	1.32537
67.5	0.00000	1.32537
68.0	0.00000	1.32537
68.5	0.00000	1.32537
69.0	0.00000	1.32537
69.5	0.00000	1.32537
70.0	0.00000	1.32537
70.5	0.00000	1.32537
71.0	0.00000	1.32537
71.5	0.00000	1.32537
72.0	0.00000	1.32537

72-Hour Long-Duration Storm Hyetograph Values for Region 4: Eastern Mountains

Note: Use 24-hour precipitation value to scale this storm hyetograph.

Time (hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.00000	0.00000
0.5	0.00000	0.00000
1.0	0.00000	0.00000
1.5	0.00000	0.00000
2.0	0.00000	0.00000
2.5	0.00000	0.00000
3.0	0.00000	0.00000
3.5	0.00000	0.00000
4.0	0.00000	0.00000
4.5	0.00000	0.00000
5.0	0.00000	0.00000
5.5	0.00000	0.00000
6.0	0.00000	0.00000
6.5	0.00300	0.00300
7.0	0.00390	0.00690
7.5	0.00423	0.01113
8.0	0.00456	0.01569
8.5	0.00490	0.02059
9.0	0.00523	0.02582
9.5	0.00556	0.03138
10.0	0.00650	0.03788
10.5	0.00868	0.04656
11.0	0.01246	0.05902
11.5	0.01824	0.07726
12.0	0.02976	0.10702
12.5	0.05160	0.15862
13.0	0.03440	0.19302
13.5	0.02655	0.21957
14.0	0.01545	0.23502
14.5	0.01388	0.24890
15.0	0.01232	0.26122
15.5	0.01089	0.27211
16.0	0.00961	0.28173
16.5	0.00848	0.29020
17.0	0.00748	0.29768
17.5	0.00661	0.30430
18.0	0.00590	0.31019
18.5	0.00532	0.31552
19.0	0.00489	0.32040
19.5	0.00459	0.32499
20.0	0.00430	0.32930
20.5	0.00401	0.33330
21.0	0.00372	0.33702
21.5	0.00343	0.34045
22.0	0.00313	0.34358
22.5	0.00284	0.34642
23.0	0.00255	0.34897
23.5	0.00226	0.35123
24.0	0.00197	0.35319
24.5	0.00000	0.35319
25.0	0.00000	0.35319
25.5	0.00000	0.35319
26.0	0.00000	0.35319
26.5	0.00000	0.35319
27.0	0.00000	0.35319
27.5	0.00000	0.35319
28.0	0.00000	0.35319
28.5	0.00000	0.35319
29.0	0.00000	0.35319
29.5	0.00000	0.35319
30.0	0.00000	0.35319
30.5	0.00000	0.35319
31.0	0.00000	0.35319
31.5	0.00000	0.35319
32.0	0.00000	0.35319
32.5	0.00000	0.35319
33.0	0.00000	0.35319
33.5	0.00000	0.35319
34.0	0.00000	0.35319
34.5	0.00000	0.35319
35.0	0.00000	0.35319
35.5	0.00000	0.35319
36.0	0.00000	0.35319
36.5	0.00167	0.35486
37.0	0.00333	0.35819
37.5	0.00510	0.36329
38.0	0.00690	0.37019
38.5	0.00879	0.37898
39.0	0.01121	0.39019
39.5	0.01240	0.40259
40.0	0.01320	0.41579
40.5	0.01400	0.42979
41.0	0.01480	0.44459
41.5	0.01560	0.46019
42.0	0.01640	0.47659
42.5	0.01720	0.49379
43.0	0.01800	0.51179
43.5	0.01880	0.53059
44.0	0.01960	0.55019
44.5	0.02050	0.57069
45.0	0.02230	0.59299
45.5	0.02500	0.61799
46.0	0.02800	0.64599
46.5	0.03000	0.67599
47.0	0.04295	0.71894
47.5	0.05720	0.77614
48.0	0.08580	0.86194
48.5	0.04751	0.90945
49.0	0.03549	0.94494
49.5	0.03265	0.97759
50.0	0.03135	1.00894
50.5	0.02140	1.03034
51.0	0.01790	1.04824
51.5	0.01670	1.06494
52.0	0.01650	1.08144
52.5	0.01630	1.09774
53.0	0.01610	1.11384
53.5	0.01590	1.12974
54.0	0.01570	1.14544
54.5	0.01550	1.16094
55.0	0.01535	1.17629
55.5	0.01508	1.19137
56.0	0.01471	1.20608
56.5	0.01442	1.22050
57.0	0.01421	1.23471
57.5	0.01407	1.24878
58.0	0.01395	1.26273
58.5	0.01385	1.27658
59.0	0.01377	1.29035
59.5	0.01370	1.30405
60.0	0.01365	1.31770
60.5	0.01358	1.33128
61.0	0.01338	1.34466
61.5	0.01300	1.35766
62.0	0.01245	1.37011
62.5	0.01174	1.38185
63.0	0.01085	1.39270
63.5	0.00975	1.40245
64.0	0.00825	1.41070
64.5	0.00654	1.41724
65.0	0.00546	1.42270
65.5	0.00484	1.42754
66.0	0.00316	1.43070
66.5	0.00000	1.43070
67.0	0.00000	1.43070
67.5	0.00000	1.43070
68.0	0.00000	1.43070
68.5	0.00000	1.43070
69.0	0.00000	1.43070
69.5	0.00000	1.43070
70.0	0.00000	1.43070
70.5	0.00000	1.43070
71.0	0.00000	1.43070
71.5	0.00000	1.43070
72.0	0.00000	1.43070